THE

JOURNAL OF GEOLOGY

JANUARY–FEBRUARY 1913

THE SECONDARY ENRICHMENT OF SILVER ORES

H. C. COOKE

INTRODUCTION

The past half-century has been a period of rapid development of mines and mining, both in America and in other countries, and as a consequence, the basal facts regarding the occurrence of ores are now comparatively well understood. The geologic causes for the location of ore-bodies in certain zones or horizons are in many cases known, and many former theories are generally accepted as facts. The transportation of ores by aqueous solutions, the origin of some of these solutions in cooling igneous magmas, and the secondary enrichment of many ore-bodies through the agency of meteoric waters; such are some of the ideas which have withstood prolonged criticism and have become established tenets of geologic faith. But beyond basal facts, adduced almost solely from field evidence, our knowledge of the mechanism of ore depositions is somewhat vague and unsatisfactory. Only prolonged investigation along chemical and physico-chemical lines will render possible a reasonably accurate understanding of the complex composition of ore-bearing solutions, of the reactions of these solutions with the wall rocks, of the causes for the deposition of minerals from them, and of many other problems connected with the deposition of ores.

At the present time the problems most important and most

amenable to solution are those of secondary enrichment; most important, because many of the most valuable deposits were concentrated in this way; most amenable to treatment, because many of the factors of the problems are known, i.e., temperature, pressure, concentrations of solutions, and the chemical nature of the reacting solutions and of the minerals affected.

The principles of secondary enrichment have been outlined by Penrose,[1] S. F. Emmons,[2] Weed,[3] Van Hise,[4] Lindgren,[5] and others, and confirmed by the work of many investigators. In a few cases the chemical reactions which take place have been studied in some detail. Brokaw[6] and McCaughey[7] have investigated the solution of gold in surface waters; Van Hise,[8] Leith, and their associates at the University of Wisconsin have studied the deposition and enrichment of the Lake Superior iron ores; Gottschalk and Buehler[9] have shown the reactions by which the sulphides of iron, lead, zinc, and other metals are taken into solution; and Allen[10] has precipitated pyrite and marcasite under natural conditions.

The processes of the secondary enrichment of silver are of much interest both because they are of widespread occurrence and because a relatively small amount of secondary enrichment may render a low-grade deposit commercially profitable. There is a great variety of secondary silver minerals, and some of them may be deposited even at considerable depths. The mechanism of this downward migration has been discussed by many writers. Near the surface, some have supposed, the silver was dissolved by sulphate solutions, others have regarded chloride waters as increasing

[1] Penrose, "Superficial Alteration of Ore Deposits," *Jour. Geol.*, II (1904), 288.

[2] S. F. Emmons, "The Secondary Enrichment of Ore Deposits," *Trans. A.I.M.E.*, XXX (1900), 177.

[3] Weed, "The Enrichment of Gold and Silver Veins," *ibid.*, p. 424.

[4] Van Hise, "Some Principles Controlling the Deposition of Ores," *ibid.*, p. 27.

[5] Lindgren, "Copper Deposits of the Clifton Morenci District," *U.S.G.S.*, XLIII (1905), 177.

[6] Brokaw, *Journal of Geology*, XVIII (1910), 321.

[7] McCaughey, *Jour. Am. Chem. Soc.*, XXXI (1909), 1263.

[8] Van Hise and Leith, *U.S.G.S. Monograph* 52 (1911).

[9] Gottschalk and Buehler, *Economic Geology*, VII (1912), 15.

[10] Allen, *Am. Jour. Sci.* (4), XXXIII (1912), 169.

the solubility, and still others have assumed the agency of carbonate waters. At greater depths, the precipitation has been thought to be due to the action of hydrogen sulphide or of other sulphides, to the reduction of sulphate solutions by organic matter, or to other causes. The work described in this paper was undertaken to test some of the hypotheses mentioned and to discover if possible in the laboratory the actual extent and speed of the reactions that were found to take place. While much remains to be done, the results herein presented are such as to indicate with some degree of certainty the probable reactions which take place in the solution of silver ores by meteoric waters, and, to a less extent, those which occur in their precipitation.

DEFINITION OF TERMS

The terms "primary" and "secondary" have not always been employed with precise meaning and their use is likely to be attended with some confusion. Wherever introduced into this paper, they are used in a genetic sense. Unless otherwise indicated, the term "primary" implies the agency of hot ascending waters; "secondary," that of cold meteoric waters. It is commonly recognized that some silver ores have been deposited by the agency of cold sulphate solutions in rocks devoid of sulphides.[1] Such deposits might be termed primary, but in their chemical aspects they are secondary, since they differ from those which ordinarily would be termed secondary only in the distance the silver solutions have been carried and in that they have been deposited outside of some zone of primary minerals. As regards their origin through the solution of some truly primary silver mineral, their method of transportation in solution, and the methods of their precipitation, they do not differ from ores precipitated in a silver lode after having been transported a short distance.

SCOPE OF THE DISCUSSION

A study of the literature of silver deposits brings out the fact that all of the silver minerals except the chloride may have either a primary or a secondary origin. These minerals include, in addi

[1] W. H. Emmons, "The Cashin Mine, Montrose Co., Colo.," *U.S.G.S. Bull.* 285 (1905), 125.

tion to compounds of silver with a single acid element, many double compounds, particularly with arsenic, antimony, and tellurium. Argentiferous galena and tetrahedrite are likewise very common sources of silver. Since a description of the secondary enrichment of any metal must account fully for the processes of its solution in meteoric waters, its transportation by, and its precipitation from, them, a complete study of the processes of the secondary enrichment of silver must involve also an explanation of the migration of the sulphides of lead, copper, arsenic, and antimony, in the same ground-waters that carry silver.

PREVIOUS WORK—EXPERIMENTAL

Experimental data bearing on this problem are few, since those who have touched the question in the laboratory have rarely worked under the conditions which commonly obtain in secondarily enriched ore deposits; i.e., low temperatures, small concentrations, low pressures, and a somewhat narrow range of possibilities in the way of chemical composition. Johnston[1] showed that silver carbonate will dissolve in water saturated with carbon dioxide at 15° C. to the extent of 0.846 gm. per liter. Senarmont[2] and Rickard[3] have demonstrated that native silver may be precipitated from silver solutions by organic or carbonaceous matter. Van Hise[4] states that silver sulphide is soluble in solutions of alkaline carbonates, but the writer has been unable to find reference to any experimental confirmation of this statement.

A few experiments have also been made under conditions within the range of possibility as to composition, though not as to temperature and pressure. Spring[5] showed that at pressures of 6,500 atmospheres silver sulphide was formed from its elements. Moesta[6] obtained metallic silver by passing steam at 100 C. over silver sul-

[1] G. S. Johnston, *Chem. N.*, LIV (1886), 75.

[2] Senarmont, *Annales Chim. Phys.*, 3d ser., XXXII (1851), 140.

[3] Rickard, *Trans. A.I.M.E.*, XXVI (1896), 978.

[4] Van Hise, *U.S.G.S. Monograph* 47 (1904), 1099.

[5] Spring, *Ber. Deutsch. Chem. Gesell.*, XVI, 324, 1002; XVII, 1218.

[6] Moesta, F. A., *Über das Vorkommen der Chlor-, Brom-, und Jodverbindungen des Silvers in der Natur; ein Beitrag zur Kenntn. d. geol. u. bergbaulichen Verhältnisse von Nord-Chile.* Marburg, 1870.

phide, and Plattner[1] obtained it by passing oxygen at 100° C.–120° C. over the same substance. Stokes[2] found that the reactions $Fe_2(SO_4)_3+2Ag=Ag_2SO_4+2FeSO_4$ and $2CuSO_4+2Ag=Cu_2SO_4+Ag_2SO_4$ were reversible; silver was dissolved on heating, and reprecipitated on cooling.

PREVIOUS WORK—FIELD DATA

Field data bearing on this problem are abundant so far as the paragenesis is concerned but few attempts have been made to discuss the problems in the light of chemical principles. The most suggestive contribution to the literature of the subject is by Weed.[3] He regards the presence of pyrite in silver lodes as prerequisite to the secondary enrichment of silver, and states that, in his experience, notable secondary enrichment has taken place only where there has been pyrite in abundance; where pyrite has not occurred in considerable amount, secondary concentration has not taken place even though all other conditions were favorable. If this relationship is true, then the solution of primary silver sulphides in meteoric waters must depend either (*a*) on the action on the silver minerals of the oxidation products of the pyrite, which may form according to the equations $FeS_2+7O+H_2O=FeSO_4+H_2SO_4$ and $2FeSO_4+H_2SO_4+O=Fe_2(SO_4)_3+H_2O$, or (*b*) on the direct oxidation of the silver minerals, due to the electrolytic action of the silver sulphide-pyrite couple, as recently described by Gottschalk and Buehler,[4] or (*c*) on a combination of these two actions.

In addition to the work of Weed, we have the evidence afforded by analyses of mine waters. While the waters collected from a mine may differ slightly in composition from the ground-waters that seeped through the undisturbed deposit, in that they are probably more dilute on account of the freer circulation of the solutions, and are also more highly oxidized on account of greater access to the atmosphere, yet nevertheless their composition approaches fairly closely that of the original ground-waters. The following tables include most of the complete analyses that have

[1] Plattner, C. F., *Die Metallurgischen Rostprocesse*. Freiberg, 1856.

[2] Stokes, *Economic Geology*, I (1906), 649.

[3] Weed, *Trans. A.I.M.E.*, XXX, 431. [4] *Op. cit.*

	1*	2*	3†	4†	5†	6†	7†
SO_4	43.2	161.7	380.38	474.0	209,100.0	173.4	272.3
Cl	7.9	186.4	1.27	19.0	127.6	0.52	13.77
CO_3	110.5	1513.4	115.0	20.5	Undetermined	47.7	241.4
SiO_2	25.9	24.4	30.5	133.4	616.0	37.8	59.9
K	10.6	198.0	8.4	53.4	.....	62.26	80.9
Na	36.4	719.4	57.1	132.0	535.0	0.27	6.86
Ca	37.4	146.4	148.1	100.1	1,286.0	72.4	113.7
Mg	12.25	177.7	154.0	5.9	6,590.0	.....	.....
Al	0.4	1.0	.....	1.37	9,670.0	.....	.....
Mn	0.8	0.6	.....	.....	885.0	.....	.....
Fe″	0.7	3.5	.....	.....	.....	.....	.....
Fe‴				6.33	5,025.0		
Acidity	.....	.....	.....	.....	147.5	.....	.....
Cu	.....	.....	.....	.....	.....	.....	.....

	8†	9‡	10‡	11§	12§	13§	14§
SO_4	160.0	7.7	7.8	258.4	26.55	280.1	124.8
Cl	16.82	3.16	3.1	Tr.	Tr.	Tr.	12.4
CO_3	194.7	141.8	146.6	.....	.....	.....	.....
SiO_2	68.9	32.7	41.4	2.1	8.0	8.8	18.0
K	254.1	1.0	1.6	.....	.....	.....	.....
Na	7.84	13.4	13.7	.....	.....	.....	.....
Ca	84.08	33.6	44.35	90.76	72.48	106.2	46.4
Mg	.....	5.7	3.35	13.1	14.9	17.1	14.5
Al	.....	.....	.....	1.5	0.4	1.5	.....
Mn	.....	0.27	1.9	4.7	4.1	1.9	.....
Fe″	.....	.....	.....	.....	.....	.....	6.6
Fe‴	Tr.	.....	.....	4.7	6.3	4.7	.....
Acidity	.....	Alkaline	Alkaline	.....	.....	.....	.....
Zn	.....	.....	.....	2.8	47.4	18.88	8.9

	15‖	16‖	17¶	18**	Average
SO_4	60.12	104.4	2039.5	327.2	179.0, excluding 5 and 17
Cl	Tr.	1.6	8.16	35.6	7.7, excluding 2 and 5
CO_3	78.3	92.4	.....	87.9	116.0, excluding 2, 5, 11–14, 17
SiO_2	32.25	23.2	43.8	64.8	38.6, excluding 5,
K	2.4	3.5	70.0	3.4	27.0, excluding 2, 5, 8, 11–14
Na	28.5	7.5	106.3	148.8	46.5, excluding 2, 5, 11–14
Ca	17.3	46.2	187.2	68.8	83.2, excluding 5
Mg	1.3	7.3	93.5	6.3	40.0, excluding 5–9
Al	.....	.....	3.12	.....	1.5, excluding 3, 5–10, 14–16, 17
Mn	0.3	3.2	155.6	0.7	2.0, excluding 3–8, 14, 17, 18
Fe″	1.5	0.9	164.8	.....	
Fe‴	.....	.....	.....	0.7	
Acidity	Alkaline	Alkaline	.....	.....	
Zn	.....	.....	49.66	.....	
Cu	.....	.....	.....	77.05	

* S. F. Emmons, 17th *Ann. Rep. U.S.G.S.*, Part 2, p. 462.
† Reed, *Bull. Dept. Geol. U. of California*, 4, pp. 189 and 192.
‡ Lindgren, 17th *Ann. Rep. U.S.G.S.*, Part 2, p. 121.
§ Beck, *Nature of Ore Deposits*, Weed's translation, II, 377.
‖ W. H. Emmons, unpublished manuscripts.
¶ L. J. W. Jones, *Proc. Colo. Sci. Soc.*, VI (1897), 48.
** R. C. Wells.

been made of the waters of gold and silver mines. For them the writer is indebted to Professor W. H. Emmons who has very kindly placed at his disposal the data which he is about to publish concerning secondary enrichment. The figures given are in parts per million.

1. Geyser silver mine, Custer Co., Colo., 500-foot level.
2. Same, 2,000-foot level.
3. Comstock lode, Savage mine, 600-foot level.
4. Comstock lode, G. and C. shaft, 2,250-foot level.
5. Comstock lode, Comstock mine, vadose water.
6. Comstock lode, Gould and Curry mine, 1,700-foot level.
7. Comstock lode, Hale and Norcross mine.
8. Comstock lode, Gould and Curry mine, 1,800-foot level.
9. Nevada City, Cal., Federal Loan mine, 400-foot level.
10. Nevada City, Cal., Black Prince mine, 400-foot level.
11–14. Rothschonberger Stolln, Freiberg, Germany.
15. Creede, Colo., Bachelor mine, 1,300-foot level.
16. Creede, Colo., Solomon mine, 1,500-foot level.
17. Idaho Springs, Colo., Stanley mine.
18. Tonopah, Nev., Mizpah mine; water from a bore hole 2,316 feet deep.

A study of these data shows clearly that the salts most abundant in mine waters are the sulphates, and further, that there is usually present an excess of acid radicles over basic; i.e., the solutions are acid in most cases. The preceding analyses are all of waters taken at some depth, hence must be assumed to be much more nearly neutral than the waters near the surface, since the tendency of descending waters is to become less acid through reaction with minerals. At Creede, as will be noted, the waters at the 1,500-foot level have actually become alkaline through the solution of carbonate in excess. It is a significant fact that this level is below the zone of secondary enrichment.[1]

The amount of ferric and ferrous salts present in the waters, as shown by the analyses, is surprisingly small. This is probably to be explained by the fact that iron salts are very easily precipitated by carbonates, which are here present in large amount. On the whole, the analyses tend to confirm the hypothesis that the active agents in the secondary processes are acid sulphate waters. They would also suggest that carbonate solutions may be a factor

[1] W. H. Emmons, unpublished manuscript.

in the processes, but this supposition should be confirmed by analyses of waters from horizons somewhat nearer the surface than those from which the above samples were taken.

EXPERIMENTAL WORK

The experimental work described in this paper deals with the following questions:

a) Solvent effect of sulphuric acid and ferric sulphate on argentite and its associated sulphides; both natural and chemically pure artificial minerals being used.

b) The solvent effect exerted on metallic silver by the various reagents that may occur in ground-waters, such as sulphates, chlorides, nascent chlorine, sulphuric and hydrochloric acids.

c) Solvent effect of ferric sulphate solutions on silver chloride.

d) Effect of the presence of ferric sulphate on the solubility of silver sulphate.

e) The equilibrium in dilute solutions between ferric, ferrous, and silver sulphates and native silver.

f) The substitution of silver for antimony or arsenic in the previously formed sulphides of these elements.

g) The reaction of metallic silver with precipitated sulphur.

As these experiments deal with somewhat widely different subjects, each series will be described and discussed separately. All of them were made under conditions approximating those which obtain in ground-waters. The temperatures were uniformly room temperatures, about 22° C. Pressures were atmospheric pressures. Concentrations of solutions were small, usually decinormal; these, although somewhat greater than those that obtain in ground-waters, may be confidently assumed to cause differences only in the speed, and not in the nature, of the reactions which take place.

The paper also includes a discussion, based on the experimental work of Barlow[1] and Schierholz,[2] of the effect of chloride solutions on the solubility of silver chloride, and the precipitation of the silver from such solutions as sulphide.

[1] Barlow, *Jour. Am. Chem. Soc.*, XXVIII (1906), 1446.

[2] Schierholz, *Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften zu Wien*, 101, 2*b* (1890), 8.

METHOD OF PROCEDURE

The mineral to be tested was first powdered. In the preliminary experiments natural minerals were used, and only that portion which would pass through a 40-mesh sieve was used. It was thought, however, that the unequal sizing of the mass of mineral so obtained might affect the results materially. Therefore in the later experiments with chemically pure materials, only the fraction that passed an 80-mesh and was held by a 100-mesh sieve was used. Of this material a certain amount, usually 1.0000 gm., was weighed out, washed into a flask, and covered with 200 c.c. of the solution whose action was to be tested. The corked flask was then set away in the dark room at room temperature. After standing for a period of from one to three months, during which time the flask was shaken almost daily, the contents were analyzed. In some cases the analysis was of the liquid contents, after the solid residue had been removed by filtration; in others, where such analysis would prove difficult, it was thought sufficient to determine the materials in solution qualitatively, and the loss of weight of the solid residue. The latter was done by filtering into a weighed Gooch crucible, drying at 120° C., and weighing. This procedure was always adopted when the minerals used were the double sulphides pyrargyrite and polybasite.

Where stibnite was the sulphide acted upon, the procedure differed, in that the solutions themselves were analyzed. This was done because of the ease of the analysis and for the greater accuracy thereby obtainable. In the absence of ferric sulphate the solutions were repeatedly evaporated to dryness in the presence of nitric acid. The resulting precipitate was then heated to a dull-red heat, whereby it was converted into the oxide Sb_2O_4, then cooled, and weighed. Where ferric sulphate was present, hydrogen sulphide was passed in until there was no further precipitate. The solution was then filtered, the filtrate being repeatedly passed through the filter until clear, after which the precipitate was dried and washed with carbon disulphide to remove excess of sulphur. The antimony trisulphide remaining on the filter was redissolved in concentrated hydrochloric acid, the resulting solution mixed with concentrated nitric acid, and cautiously evaporated on a water

bath. As fast as the solution became colorless, more nitric acid was added, until further addition caused no change of color. The solution was then evaporated to dryness, the precipitate heated to a red heat, cooled, and weighed. Trial of this method with a weighed amount of pure antimony trisulphide showed it accurate to 1 per cent.

MAKING UP SOLUTIONS

A ferric sulphate solution was made, containing 35 grams of Kalhbaum's C.P. powdered ferric sulphate per liter. This gave a solution nearly F/20 (actually 0.0535 F. An F/1 solution = solution containing 1 formula weight in grams per liter). The sulphuric acid solution used was roughly F/20. That used in the first series of experiments was 0.0635 F; that used in the second series, 0.0502 F. These solutions will hereafter be mentioned simply as "ferric sulphate solution" and "decinormal sulphuric acid," and in the tables will be designated as "F" and "A," for brevity. A proportionality, such as A:F::1:3, indicates the proportions of acid and ferric solutions. The total volume of all solutions, unless otherwise stated, is 200 c.c.

ACTION OF SOLUTIONS ON MINERALS. SERIES 1

As may be seen from the tables, this series of tests included not only the silver minerals, but also those with which it is most closely associated, i.e., the sulphides of arsenic, antimony, and lead. Copper sulphide was not tested, since Vogt[1] had already proved its ready solubility in ferric solutions. The table also shows that both the dilute sulphuric acid and the dilute ferric sulphate solutions exert a powerful solvent action on all the minerals tested except argentite; that in each case the action is much more powerful when ferric sulphate is present; and that, except in the case of galena, an increase in the concentration of the ferric sulphate does not cause a corresponding increase in the solvent action. The absence of results in the case of the lump argentite is rather to be ascribed to the smallness of the surface exposed than to an actual absence of action. This will be shown in the table (Series 2).

[1] Vogt, *Genesis of Ore Deposits* (1896), p. 676, footnote.

SERIES 1

Solution	Mineral	Loss of Weight	Time	Remarks
H_2SO_4.....	Pyrargyrite 1.000 gm.	0.0130 gm.	81 days	Solution contained Sb, Ag
Acid: Fer. Sulph. = 3:1 .	Pyrargyrite 1.000 gm.	.0290	81	Solution contained Sb, Ag
A:F::1:1...	Pyrargyrite 1.000 gm.	0.0272	81	Solution contained Sb, Ag
A:F::1:3..	Pyrargyrite 1.000 gm.	0.0268	81	Solution contained Sb, Ag
A.....	Polybasite	.0075	81	Solution contained Sb, Ag
A:F::1:1...	Polybasite	.0212	81	Solution contained Sb, Ag
A.....	Argentite, lump	.0000	83	
A:F::3:1...	Argentite, lump	.0000	83	
A:F::1:1...	Argentite, lump	.0002	83	
A:F::1:3...	Argentite, lump	.0022	83	
Water.....	Argentite, lump	.0010	83	
A.....	Orpiment	0.0108	81	Solution contained As
A:F::1:1...	Orpiment	.0780	81	Solution contained As
Water.....	Stibnite	.....	102	Some sol. lost. Test gave a little Sb and SO_4
A.....	Stibnite	.....	102	Solution analyzed, yielded .0185 gm. Sb_2O_4
A:F::1:1...	Stibnite	.....	102	Solution analyzed, yielded .0255 gm. Sb_2O_4 solutions of 500 c.c. in each case
A.....	Galena 1.000 gm.	.0714 gm. gain of weight	81	Residues gained in weight due to formation of $PbSO_4$. 75 c.c. of solution used in each case
A:F::2:2...	Galena	.0924 gm. gain	81	
A:F::1:2...	Galena	.1700 gm. gain	81	

The fact that the solubility of the sulphides is so much greater in the presence of ferric sulphate, but is not at all proportional to the concentration of the latter salt, is probably to be explained by the hypothesis that the active agent is really the sulphuric acid, while the ferric sulphate exerts little direct action. The reaction of sulphuric acid on a sulphide may be represented by the equation $Ag_2S+H_2SO_4=Ag_2SO_4+H_2S$. This reaction, like most others, comes to an equilibrium. It must stop as soon as the product of the concentrations of the silver ion and the sulphide ion in the solution becomes equal to the solubility product of the sulphide acted upon (in this case Ag_2S). As the solubility products of most of the insoluble sulphides are very small,[1] the reaction in these cases can proceed but for an almost immeasurably short distance before stopping. But if some substance present remove the hydrogen sulphide as fast as formed, the reaction may proceed till all the ferric sulphate is used up. This is probably the main function of the ferric sulphate, which reacts thus with hydrogen sulphide: $Fe_2(SO_4)_3+H_2S=2FeSO_4+H_2SO_4+S$. If this be the true explanation of the action of the ferric sulphate, then it is to be expected that a small amount of ferric sulphate would cause as powerful a solvent action as a larger amount. The increased action in solutions more concentrated in ferric sulphate, shown especially in the case of the galena, may be ascribed either to a direct oxidizing effect of the sulphate on the sulphide or to the increased speed with which the more concentrated sulphate solution destroys the hydrogen sulphide formed.

If this explanation of the function of the ferric solution be the true one, two questions naturally arise: (*a*) Why is a measurable loss obtained experimentally when pure sulphuric acid acts on the sulphides? and (*b*) Was the reaction really at an end when the measurements taken in the experiments were made? In answer to question (*a*) the writer suggests that the oxygen of the air acts like the ferric sulphate, in removing hydrogen sulphide from solution, thus: $H_2S+O=H_2O+S$; its action is much slower than that of the ferric sulphate, however, so that the action of the acid on the

[1] Knox, *Trans. Faraday Soc.*, IV (1908), Part I, p. 29. Knox determined the solubility product of Ag_2S as 3.9×10^{-50}; of CuS as 1.2×10^{-42}; of PbS as 2.6×10^{-15}.

sulphide is less. In answer to question (*b*), we must conclude in the light of the hypothesis given that the action of the acid on the sulphide was not at an end, nor would it end till the ferric salt or the sulphide was used up. This might be tested by a series of experiments similar to the above, and lasting for a year or more; but time did not permit such test.

ACTION OF SOLUTIONS ON MINERALS. SERIES 2

To make certain that the losses in weight obtained in the last table were not due to the presence of soluble impurities in the natural sulphides, some of the above experiments were repeated with chemically pure substances. For the pyrargyrite used the writer is indebted to Mr. Sayrs A. Garlick, of the department of chemistry, who prepared it according to Sommerlad's method.[1] The other substances were prepared by the writer. The results are given in the following table.

SERIES 2

Solution	Mineral	Loss of Weight	Time	Remarks
Water	Argentite	0.0010 gm.	98 days	
A	Argentite	.0019	98	
A:F::3:1	Argentite	.0062	98	
A:F::1:3	Argentite	.0074	98	
Water	Pyrargyrite	.0111	101	
A	Pyrargyrite	.0093	101	
A:F::3:1	Pyrargyrite	.0120	101	
A:F::1:1	Pyrargyrite	.0125	101	
A:F::1:3	Pyrargyrite	.0144	101	
Water	Stibnite	.0175	84	Weights give weight of Sb_2O_4 obtained from analysis of solutions
A	Stibnite	.0205	84	
A:F::3:1	Stibnite	.0185	84	
A:F::1:3	Stibnite	.0160	84	
F	Silver chloride	.....	33	Solutions gave no Ag
F:H_2O::1:1	Silver chloride	.0000	33	
N/5 H_2SO_4	Silver chloride	.0000	33	

It will be seen therefore that the reactions noted in Series 1 and 2 are of the same class. The values obtained in Series 2 are perhaps somewhat smaller than those in Series 1, but this may have

[1] H. Sommerlad, *Zeit. anorg. Chemie*, XV (1897), 173.

been due to the presence of a soluble impurity in the natural minerals; or perhaps the artificial materials may actually dissolve less readily than the natural. The results obtained from Series 1 are, however, fairly well substantiated, and the additional conclusion might be drawn that, in the case of the double compounds of silver with antimony or arsenic, it is the silver which is the less soluble constituent. This result is inferred from observation of pyrargyrite during the reaction; it turned black within a very few days, an effect which could be due only to accumulation of silver sulphide on its surface as antimony was leached out. The writer did not confirm this conclusion by analysis, however.

EFFECT OF NATURAL REAGENTS ON METALLIC SILVER

In the investigation of the effects that the substances in solution in natural waters might have upon metallic silver, the reagents used were sodium chloride solution, hydrochloric acid solution acidified with sulphuric acid, in the presence of manganese dioxide so as to insure the presence of nascent chlorine, sulphuric acid solution, and ferric sulphate solution. The silver used was chemically pure leaf silver, cut into pieces about 2 sq. cm. in area, freed from all tarnish by scraping with a dull knife, and weighed to 0.00001 gm. on an assay balance. These were placed in large test tubes, covered with 75 c.c. of solution in each case, tightly corked, and placed in the dark for 73 days at room temperature (22° C.). At the close of the time mentioned they were taken out, carefully washed and dried, and weighed. In the cases where the silver had been covered with a coating of chloride, this was removed before weighing by washing with ammonia.

Solution	Loss of Weight of Silver
N/10 NaCl	0.00000 gm.
N/10 NaCl:N/10 H_2SO_4::1:1+MnO_2	.01538
N/10 HCl	.04502
N/10 H_2SO_4	.00019
A:F::1:1	.08252

These experiments show clearly the powerful solvent effect exerted by ferric solutions on native silver. It is probably this reagent which leaches the silver from the outer zones of gold

nuggets.[1] The conclusion might also be drawn that the formation of native silver would take place to but a limited extent in the gossans of deposits containing much pyrite.

The solvent action of the acids in the above table is ascribed to the presence of air, which sets up an oxidation potential between the silver and the solution, and thus aids the solution of the silver. Acids cannot attack silver directly in the absence of air, since the solution tension of the silver is less than that of the hydrogen which would thereby be given off. This fact may account in part for the stability of native silver precipitated below the zone of oxidation.

ACTION OF FERRIC SULPHATE ON SILVER SULPHATE

During the course of the above experiments, in some cases unusually high concentrations of silver were noted in the solutions. The solubility of silver sulphate in pure water at room temperature, 22° C., determined by measuring the strength of a solution that had been standing with frequent shaking for some months in contact with solid silver sulphate in the dark, was 6.90 gm. per liter or 0.0211 F. Euler[2] gives a figure somewhat higher than this, 7.70 gm. per liter at 17° C. Wright and Thompson[3] give 7.28 per liter at 18° C. The addition of an ionized sulphate, such as ferric sulphate, would be expected to decrease the solubility of the silver sulphate; since in a saturated solution the ion product $[Ag]^2 \times [SO_4]$ must be a constant. This is not the case here, however. Experiments carried out by leaving solid silver sulphate in contact with ferric sulphate solutions of varying strengths for a month or more in the dark show that the concentration of the silver is actually very considerably higher in the ferric solutions than in the aqueous. The following table (p. 16) shows the results obtained.

It will be noted that even in the most dilute of these solutions the solubility of the silver sulphate is increased by about 10 per cent. The results in the higher concentrations, while interesting from a scientific point of view, are of no significance as regards secondary

[1] J. M. McLaren, *Gold* (1908), p. 22.

[2] Euler, *Zeit. physik. Chem.*, XLIX (1904), 314.

[3] *Phil. Mag.* (5), XVII (1884), 288.

Strength of Ferric Solution	Concentration of Silver in Solution
0.0000 formula wt. per liter	0.0211 formula wt. Ag_2SO_4 per liter
0.0067	.02324
.0134	.02404
.0267	.02404
.0401	.02476
.0535	.02470
.062	.02508
.124	.02657
.248	.03012
.372	.02908
.496	.02864
.620	.03123

enrichment, as the concentration of ferric salt in earth waters probably never exceeds 0.05 F.

The cause of this behavior may be as follows: silver sulphate ionizes primarily into the ions Ag and $AgSO_4$, secondarily into the ions 2Ag and SO_4. The concentration of the silver *ions* is absolutely limited by the equation $\frac{[Ag]^2 \times [SO]_4}{Ag_2So_4} = a$ constant. The addition of a large concentration of sulphate ions, as by the addition of ferric sulphate, must correspondingly decrease the concentration of the silver *ion* present. Since, however, the concentration of the silver in the solution increases, much of the silver must be present in some non-ionized form. The recent work of Harkins[1] would make it seem probable that the silver is present as part of the complex ion $AgSO_4$, the solubility of which would of course not be affected by the presence of the SO_4 ion.

EQUILIBRIUM BETWEEN FERRIC, FERROUS, AND SILVER SULPHATES

The reaction $Fe_2(SO_4)_3 + 2Ag = 2FeSO_4 + Ag_2SO_4$ has already been studied by Stokes,[2] and the fact noted that it is an equilibrium reaction, which proceeds to the right with rising temperature. In ore deposits where secondary enrichment is going on, the ferric sulphate formed in the upper parts of the oxidized zone must be

[1] Harkins, *Jour. Am. Chem. Soc.*, XXXIII (1911), 1836.

[2] Stokes, *loc. cit.*

gradually changed to the ferrous state as the solutions descend, by reaction with hydrogen sulphide sulphides and other reducing agents. A descending solution containing ferric, ferrous, and silver sulphates may thus react with the sulphides with which it comes in contact, perhaps taking more silver into solution, until the concentration of the ferrous salt present reaches a definite relation to that of the ferric and silver salts, expressible by the equation

$$\frac{C_{Fe}''' \times C_{Ag}}{C_{Fe}'' \times C_{Ag}'} = K$$

where

C_{Fe}''' . . . . = concentration of ferric ion in solution
C_{Fe}'' . . . . = concentration of ferrous ion in solution
C_{Ag}' . . . . = concentration of silver ion in solution
C_{Ag} . . . . = concentration of metallic silver in solution
K = a constant

Since C_{Ag} is extremely small and a constant, we may divide both members of the equation by it, and obtain

$$\frac{C_{Fe}'''}{C_{Fe}'' \times C_{Ag}'} = \frac{K}{C_{Ag}} = K_2, \text{ a constant.}$$

It is evident that, given this constant, and an analysis of the earth waters containing the salts mentioned, at various depths, the horizon at which solution would cease and precipitation would begin can be determined. It becomes, therefore, a matter of importance to determine the value of the constant. To accomplish this, a ferrous sulphate solution was made of about F/20 in strength, by dissolving chemically pure ferrous sulphate in N/50 sulphuric acid solution. The ferrous content of this solution was then determined by standard potassium permanganate, the total iron by reduction with test lead and titration with permanganate, and the total sulphate by precipitation as barium sulphate. To 100-c.c. portions of this solution were then added quantities of a saturated silver sulphate solution varying from 10 c.c. to 100 c.c.; the flasks were immediately corked, the whole securely sealed with melted paraffin to prevent access of air, and set away to come to equilibrium. German standard pipettes were used throughout in measuring the solutions. Precipitation of silver, which came down as a cloud of silvery flakes, took place almost at once, and equilibrium was

probably reached in a few hours; but owing to delays the solutions remained for 65 days before they were analyzed. They were shaken at intervals during this time. In the analyses, the ferrous salt was first determined by standard permanganate; great care being taken to stop the titration as the first faint tinge of pink appeared. The silver was determined in the same sample by titration with ammonium thiocyanate.[1] The method was found very accurate, duplicates checking to one-tenth of 1 per cent. The ferric salt was determined by difference. In calculating the constant from the results obtained, it was assumed that the salts were all completely ionized in the dilute solutions used. This assumption is scarcely permissible; but the writer was unable to obtain any figures on the ionization of ferric sulphate in solutions of different strengths and for the other salts the difference between complete ionization and their ionization in these solutions is small. Concentrations in the following table are all given in formula weights per liter.

$Fe_2(SO_4)_3$	$FeSO_4$	Ag_2SO_4	K_3
0.00370	0.03972	0.000439	212.1
.00475	.03370	.000703	200.4
.00556	.02876	.000952	203.2
.00626	.02451	.001298	196.7
.00677	.02101	.001708	188.8
.00695	.01849	.002294	163.5
.00718	.01614	.002738	162.5
.00737	.01406	.003226	162.5
.00748	.01231	.003715	163.7
.00749	.01094	.004200	163.0

From the results of the last five analyses the constant would be 163. The higher results of the first five analyses are ascribed to increasing hydrolysis of the ferric salt as its dilution increases. This would make the amount of the ferric *ion* in solution less than the total ferric value. It is the latter which is measured, while only the ionized portion enters into the equilibrium. Therefore, since in the fraction $\frac{C_{Fe'''}}{C_{Fe''} \times C_{Ag'}}$ the numerator is too large, the value of the fraction must likewise be too large. If this is the true

[1] Volhard, *Liebig's Ann. d. Chem.*, CXC, 1.

cause of the increase of K_2, an increase of the acidity of the solution by addition of sulphuric acid should bring K_2 back to its true value, by decreasing the hydrolysis of the ferric sulphate. This, however, has not yet been experimentally verified.

This constant is given with some hesitation; it should be verified by further experimental work before final acceptance. Moreover, as it stands it expresses a relation merely between the concentrations of the various salts involved, not between the concentrations of their ions; but in the absence of accurate determinations of the extent of ionization of these salts, this is unavoidable.

REACTION OF SILVER CHLORIDE WITH SODIUM CHLORIDE

The question of the secondary enrichment of silver deposits through the agency of chloride solutions has long been discussed. Silver chloride has a solubility in water of 0.0016 gm. per liter at 20° C.[1] It has often been stated that the presence of sodium chloride in the water increases the solubility. The information already at hand in regard to this question is comprised in the following table:

NaCl in Solution	AgCl in Solution	Temperature
gm. per liter	gm. per liter	
34.3	0.0018	20° C.**
46.0	.0025	20° C.
57.5	.0047	20° C.
76.7	.0125	20° C.
115.0	.031	20 °C.
153.0	.090	20° C.
230.0	.313	20° C.
100.0	.025	15° C.†
142.9	.071	15° C.
181.8	.182	15° C.
219.8	.439	15° C.
235.3	.706	15° C.
256.4	1.03	15° C.
263.1	1.27	15° C.

** Barlow, *Jour. Am. Chem. Soc.*, XXVIII (1906), 446.

† Schierholtz, *Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften zu Wien*, 101, 2b (1890), 8.

Thus it requires the presence in solution of 34.3 gm. of sodium chloride per liter, or 34,300 parts per million, to raise the solubility of the silver chloride to its value in pure water. In all sodium

[1] Kohlrausch, *Zeit. phys. Chem.*, L, 356.

chloride solution of less strength the solubility of the silver chloride must be less than its solubility in pure water; the solubility curve will consequently be as shown in Fig. 1, which was obtained as follows: silver in chloride solutions exists in two forms, as silver ion and as part of some non-ionized molecule or some complex ion. The concentration of the silver ion in solution is inversely proportional to that of the chloride ion according to the equation $C_{Ag} \times C_{Cl} = k$, a constant. Hence addition of sodium chloride to silver chloride solution will very rapidly reduce the concentration of silver ion to a very small quantity (see Fig. 1). Silver in the non-ionic form may be present as molecular silver chloride, but the amount of this is so small as to be negligible; it may also be present in combination with sodium chloride, forming compounds of composition as yet undetermined, but which may be supposed, from analogy with the corresponding cyanide compounds, to have the formulae $NaAgCl_2$ or Na_2AgCl_3. The silver would then enter into solution as part of the complex negative ion $AgCl_2'$ or $AgCl_3''$, whose solubility would not be affected by the presence of chloride ion. The table shows that the amount of AgCl in solution as complex ion attains 0.0018 gm. per liter only when the amount of sodium chloride present is 34.3 gm. per liter, and that thereafter the concentration of complex ion increases proportionally much faster than does the concentration of the soldium chloride; hence it is probable that in sodium chloride solutions of strength less than 34.3 gm. per liter the concentration of complex ion, and therefore that of silver, will never be more than proportional to the amount of sodium chloride present, but usually less. The curve showing the total silver in solution will consequently be of the form shown in Fig. 1.

From these experiments, therefore, it is concluded that only when the amount of sodium chloride in ground-waters exceeds 34.3 gm. per liter may such waters be solvents superior to those in which chlorides are absent. Such concentrations occur rarely in nature.

An accurate determination of the strength of the sodium chloride solution which contains the minimum amount of silver chloride will be of value as rendering possible the determination of the

causes of secondary cerargyrite enrichment in any deposit, because silver solutions containing less sodium chloride than this "mini-

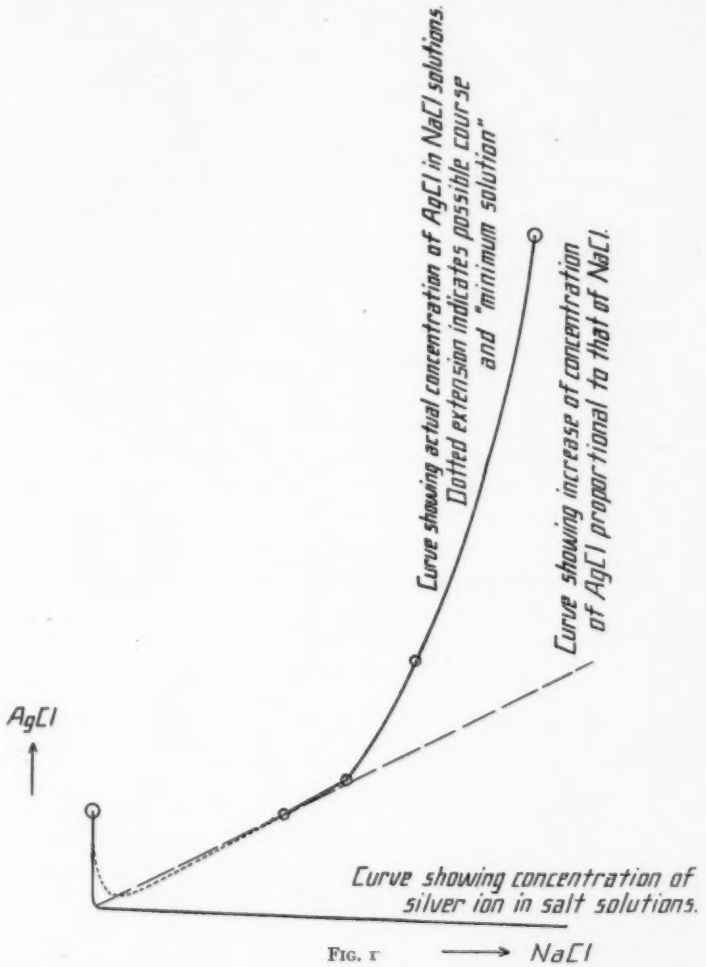

Curve showing actual concentration of AgCl in NaCl solutions.
Dotted extension indicates possible course and "minimum solution"
Curve showing increase of concentration of AgCl proportional to that of NaCl.
AgCl
Curve showing concentration of silver ion in salt solutions.
NaCl

FIG. 1

mum solution" will precipitate silver chloride if the concentration of the sodium chloride increases; while, on the contrary, silver solu-

tions in which more sodium chloride is present than in the "minimum solution" will precipitate silver chloride *on dilution*.

Can the addition of sodium chloride to silver chloride solutions ever so reduce the amount of silver present that the precipitation of silver as sulphide becomes impossible?

This relation is determinable mathematically. The solubility of silver chloride in water at 20° C. is 0.0016 gm., or 1.1×10^{-5} mols per liter. Assuming complete dissociation, as is permissible at such dilutions for a salt of a strong acid and a strong base, we should have present in solution 1.1×10^{-5} mols of Ag ion, and the same number of mols of Cl ion. The solubility product for the salt is therefore $(1.1\times10^{-5})^2=1.24\times10^{-10}$.

The concentration of silver sulphide aqueous solution is 2.2×10^{-17} mols per liter,[1] and at such extreme dilution the salt may be assumed to be completely ionized. The amount of Ag ion present in a saturated solution is therefore 4.4×10^{-17} mols per liter, and the amount of sulphur ion, one-half of this.

The addition of sodium chloride to silver chloride solution, as before shown, decreases the amount of silver ion present in solution. To prevent the precipitation of the silver as sulphide, the amount of silver ion would have to be decreased till the product of the silver ion and the sulphur ion present in solution was equal to the solubility product for silver sulphide, i.e., 3.9×10^{-50}. If we assume the concentration of sulphur ion never greater than the amount given above, 2.2×10^{-17}, then the concentration of the silver ion must decrease to 4.4×10^{-17} if precipitation is not to occur. Substituting this value into the equation $C_{Ag}\times C_{Cl}=1.24\times10^{-10}$, we obtain 2.8×10^{6} as the value of the Cl ion. Disregarding the infinitesimal amount of Cl ion in combination with Ag ion, we should therefore require to have present 2.8 million mols, or about 165 million grams, of ionized sodium chloride per liter, to prevent the formation of silver sulphide under the given conditions. With higher concentrations of sulphur ion, even more sodium chloride would be required to prevent the formation of silver sulphide. As such concentrations of sodium chloride are impossible, it is evident that the amount of this salt in meteoric waters can

[1] Knox, *loc. cit.*

never rise so high as to bar the precipitation of silver as sulphide from solutions in which it is carried as chloride.

MECHANISM OF THE SOLUTION OF SILVER MINERALS IN METEORIC WATERS

The work of Gottschalk and Buehler, coupled with that of the writer, renders possible a statement of the method by which the silver sulphides are taken into solution in the ground-water. The potentials of the minerals studied by Gottschalk and Buehler, measured against that of copper, include marcasite, +0.37 volt; argentite, +0.27 volt; pyrite, +0.18 volt. If we assume then an ore-body of argentite and pyrite, the pyrite, whose potential is lower than that of the argentite, will be oxidized, while the argentite is protected from *direct* oxidation. The silver can then be taken into solution only by the secondary action of the oxidation products of the pyrite, ferric sulphate, and sulphuric acid. But if the iron sulphide of the deposit be marcasite—a rare case—then we might expect a *direct* oxidation of the silver sulphide to sulphate by the electrolytic action set up since marcasite possesses a higher potential than argentite.

Moreover, the iron sulphides are *the only sulphides* which can effect the solution of the argentite. The potential of argentite is higher than that of the sulphide of any other metal except iron, hence it can undergo *direct* oxidation only in the presence of iron sulphide; and since no sulphides but those of iron produce by oxidation the solvents ferric sulphate and sulphuric acid, argentite can undergo *indirect* oxidation likewise only in the presence of iron sulphide. Therefore Weed's deduction, that the secondary enrichment of silver is dependent on the presence of pyrite in the lodes, appears to be confirmed.

FORMATION OF SILVER SULPHIDE

The formation of the complex silver minerals by simultaneous precipitation of the component sulphides was not attempted, on account of lack of facilities for handling large volumes of dilute solutions. It was thought, however, that these might be formed by substitution of silver for arsenic or antimony in the pre-existing

sulphides of these elements. To test this theory, well-crystallized specimens of realgar, orpiment, and stibnite were powdered, the stibnite to pass an 80-mesh, the others a 40-mesh screen. The stibnite was covered with a saturated (about N/30) silver sulphate solution, the realgar and orpiment with N/40 silver nitrate solutions, after which the mixtures were put away in the dark. The stibnite was analyzed after 36 days, the realgar and orpiment after 68 days, the analyses being conducted by passing a current of dry chlorine over the material heated to a low red heat. The silver remained in the tube as silver chloride, together with earthy impurities; the other substances volatilized as chlorides. After weighing, the silver chloride was dissolved with warm ammonia, and the weight of the impurities determined. Results were:

Stibnite contained 1.3 per cent Ag
Realgar contained 1.9 per cent Ag
Orpiment contained 9.8 per cent Ag

Since pyrargyrite contains 60 per cent and proustite 65 per cent of silver, the amounts of silver entering into the sulphides in these experiments were far below those necessary to give a true silver mineral. Moreover, the reaction in the case of the orpiment was visibly instantaneous, the powder changing from brilliant yellow to black at once. As the solutions used contained much more silver than ground-waters commonly do, it would appear improbable that true silver minerals are formed in this way.

The formation of argentite can easily be explained by the action of hydrogen sulphide or a metallic sulphide on silver-bearing solutions. As has been shown by R. C. Wells,[1] the action of dilute sulphuric acid on pyrrhotite, galena, sphalerite, and other natural sulphides produces hydrogen sulphide. This might be supposed to react with the silver solution and yield silver sulphide, and, as already mentioned, would do so in the case of chloride solutions carrying silver. But in the case of sulphate solutions a complication is introduced. Hydrogen sulphide would probably precipitate the silver as sulphide here also, but it tends in addition to attack the ferric sulphate present in the solutions, and to reduce it to the ferrous form with separation of sulphur. The formation of ferrous

[1] R. C. Wells, unpublished manuscript.

salt would precipitate silver from solution as metal, so that a mixture of sulphur and metallic silver might result. Sulphur in the ordinary form will not react with silver, except under very high pressures,[1] which cannot be assumed under the conditions existing. However, as has been recently shown,[2] precipitated sulphur is not crystalline, but amorphous, and might therefore be expected to possess a greater chemical activity than crystalline sulphur. To test this, an acid solution of ferric sulphate was partially reduced to ferrous salt by passing in hydrogen sulphide, after which it was allowed to stand for a few minutes in order that all the hydrogen sulphide in solution might be used up. Some silver previously precipitated by reaction of ferrous sulphate with silver sulphate was then added. Reaction did not occur at once, but at the end of twenty-four hours all of the silver had been altered from silvery white flakes to black silver sulphide. To make certain that the black mass did not consist of marcasite, as might be suspected from the work of Allen,[3] some sulphur was precipitated by treating sodium thiosulphate with sulphuric acid, filtered, washed, and added to some washed silver prepared as before. The results were the same, hence the end product of the reaction of hydrogen sulphide with silver solutions is silver sulphide, whether it is the first product of precipitation or not.

The conclusion may also be drawn from this reaction, that if in any deposit native silver were the first product precipitated, and at some subsequent time sulphur were also formed there, then the sulphur and silver would combine to form argentite, the completeness of the alteration depending on the amount of sulphur. Such a hypothesis might possibly account for the mixtures of secondary argentite and native silver found at depths in some deposits, notably at Creede, Colo.

SUMMARY

Secondary sulphide enrichment of a primary silver deposit is brought about by reactions of silver or its sulphides with the sulphides of iron and their products of oxidation.

[1] Spring, *loc. cit.*

[2] Brownlee, *Jour. Am. Chem. Soc.*, XXIX (1907), 1032.

[3] Allen, *loc. cit.*

When the iron sulphide present is pyrite, the silver sulphide is converted into sulphate wholly by the sulphuric acid and the ferric sulphate produced by the oxidation of the pyrite, according to the equation on p. 5.

When marcasite is present, as it rarely is in quantity, silver sulphide may be oxidized in part directly to silver sulphate by electrolytic action, and in part may be converted into sulphate by the action of the oxidation products of the marcasite.

Sulphuric acid and ferric sulphate exert a powerful solvent action both on silver sulphide and on its companion sulphides, such as galena, chalcocite, orpiment, and stibnite. Of these, silver sulphide is the least affected. In all cases the action is much more powerful when ferric sulphate is present than when sulphuric acid acts alone.

Except in the case of galena, the solvent action does not seem to be proportional to the concentration of the ferric sulphate present. This suggests that the sulphuric acid is really the active agent, and that the ferric sulphate acts principally as an agent for the removal from solution of hydrogen sulphide formed during the reaction.

A mixture of sulphuric acid and ferric sulphate has a powerful solvent action on metallic silver, hence, in an ore-body containing much pyrite, little native silver may be expected in the gossan; and conversely, if much native silver be found in the gossan, the ore-body cannot have contained much pyrite, and little secondary enrichment should be expected.

The presence of ferric sulphate in the ground-waters increases the solubility of silver sulphate in them. This is probably due to the formation of a complex ion $AgSO_4$ by the silver, when ferric sulphate is present in solution.

Equilibrium in silver-bearing solutions between ferric, ferrous, and silver sulphates is such that the reduction of ferric solutions to the ferrous condition by any means will rapidly precipitate the silver in the metallic form. Precipitation of silver will not cease till all the ferric salt is reduced to the ferrous state. Hence the vertical extent of the zone of precipitation and its proximity to the surface will depend on the rapidity with which this reduction goes on. If reduction be slow, native silver may thus be formed even

at considerable depths. Native silver so precipitated will be comparatively stable in the presence of earth waters. Acids will not attack it in the absence of oxygen, since the solution pressure of hydrogen is greater than that of silver. Ferric sulphate cannot attack it so long as the ground-waters contain enough silver sulphate to preserve equilibrium between the ferric and ferrous salts. Precipitated sulphur may convert it into sulphide.

The presence of sodium chloride in ground-water does not increase the solubility of silver chloride therein, unless the amount of sodium chloride rises above 34.3 gm. per liter; on the contrary, it decreases the solubility. The solubility-curve of silver chloride in sodium chloride solutions is shown in Fig. 1. Terming the sodium chloride solution which contains the least amount of silver chloride the "minimum solution," then solutions which contain less sodium chloride than this minimum solution will precipitate silver chloride on taking up more sodium chloride; solutions with more sodium chloride than the minimum solution will precipitate silver chloride on dilution.

Silver chloride solutions containing sodium chloride in any concentration may form secondary silver sulphide wherever they encounter hydrogen sulphide or any other substance that yields sulphur ion even in minute quantity.

Cerargyrite appears to be stable in presence of sulphuric acid and ferric sulphate.

The action of dilute silver solutions on realgar, orpiment, and stibnite results in the substitution into these minerals of some silver; but the amounts so substituted were found to be so small that it appears doubtful whether the complex sulpho-salts of silver can be formed in this way.

Precipitated sulphur combines with precipitated silver at ordinary temperature and pressure to form silver sulphide. Silver sulphide is also formed by the direct reaction of hydrogen sulphide with silver-bearing solutions.

CONCLUSION

The accuracy of the application of laboratory investigations to geologic problems must be verified by field observations; otherwise, however correct the experimental work, it cannot be claimed

to solve the problem attacked. The data at hand dealing with the secondary enrichment of silver are scarcely complete enough to make such verification of this work at the present time. The full solution of the problem would require (*a*) approximately accurate estimates of the proportions in which pyrite, primary silver sulphide, and secondary silver sulphides are present, in a large number of deposits; (*b*) more analyses of mine waters, and especially of waters from the same mine at different depths; (*c*) further observations on the changes in chemical and mineralogical composition of lodes with depth; (*d*) accurate analyses of the thin veinlets of secondary material that cut primary sulphide ores; (*e*) in cerargyrite deposits, analyses of the waters at top and bottom of the cerargyrite zone. Such data would at once render it possible to determine whether or not the processes of the secondary enrichment were subject to factors other than those mentioned in this paper.

In conclusion, the writer wishes to express his thanks to Professor W. H. Emmons, who suggested this research and generously placed at the writer's disposal his invaluable fund of practical information on the subject. He also wishes to make grateful acknowledgment to Professor Julius Stieglitz for much kind assistance and valuable criticism; and to Mr. A. D. Brokaw for many useful suggestions. As regards the work of this paper, the writer recognizes the incomplete and, as it were, qualitative nature of many of the results obtained; this, however, was unavoidable on account of the preliminary nature of the work, the large field covered, and the limited time at his disposal. It is his aim to investigate more accurately in the near future many of the problems as yet but incompletely solved.

THE GEOLOGY OF LUZON, P.I.

WARREN D. SMITH, PH.D.
Chief of Division of Mines, Bureau of Science, Manila, Philippine Islands[1]

CONTENTS

INTRODUCTION

PHYSIOGRAPHY
- The Coastal Plains
- The Central Plain
- The Albay Plain
- The Intermediate Uplands
- The Cordilleras
- The Rivers
- The Lakes and Swamps
- Human Response

GEOLOGY
- General Considerations
- The Igneous Complex (Pretertiary (?) Rocks)
- The Metamorphic Rocks
- The Tertiary Sediments
- Recent Formations

ECONOMIC
- Coal
- Iron
- Oil
- Gold
- Copper

INTRODUCTION

Luzon is the largest island of the Philippine group and, if not now, promises soon to be the most important island off the eastern coast of Asia. Because of its great strategic importance and because it is the home of the only Christianized people of Malay origin, it is of more than passing interest. Geologically, it is worthy of constant study as it is a link in that great "Circle of Fire" which girds the Pacific. From it, doubtless, are to be wrested

[1] Published with the permission of the Director, Bureau of Science, Manila.

important secrets relating to such questions as the former configuration of Asia, climatic changes, and possibly something of the early history of man. As a mining field, evidence is already abundant that Luzon will before many years have a place in the very first rank.

Finally, Manila, the capital of Luzon, through her Bureau of Science, an institution not surpassed anywhere in the Orient, will be the point from which, possibly, all the geology of the Orient will be correlated.

The dominant feature about Luzon, as is the case with other portions of the Archipelago, is the enormous coast line and the mountainous character of much of its interior. The effects on the character and pursuits of the people have been great. Some of these will be alluded to farther on in this paper. Luzon's geographical position is also noteworthy. She is in a region of tremendous rainfall (45 inches in 24 hours, Baguio Observatory record, July, 1911) and in the track of the most frequent and violent typhoons. As she extends from 10° to 21° north latitude and has much high level country, which is at the same time fertile, she could be colonized by white men.

PHYSIOGRAPHY

THE COASTAL PLAINS

The coastal plains about the Island of Luzon, are, as a rule, very narrow, the maximum width being about 10 miles. The mountains are nearly everywhere close to the sea. The best development of coastal plains is to be found north from Lingayen Gulf, because the northern part of Luzon has been longest under water, and erosion has had time to work on the mountains, carrying detritus down to the sea. The composition of the northern coastal plain consists almost entirely of alluvial and Piedmont deposits. Another fair development of coastal plain is found on both sides of the Tayabas Peninsula and around Batangas Bay. The east coast of Luzon is conspicuously lacking in broad coastal plains. It is a fact that the east coast is sinking in part, while the west coast is known to be rising in part. As evidence of this, I am citing the raised beaches and terraces along the Ilocos Norte coast on the

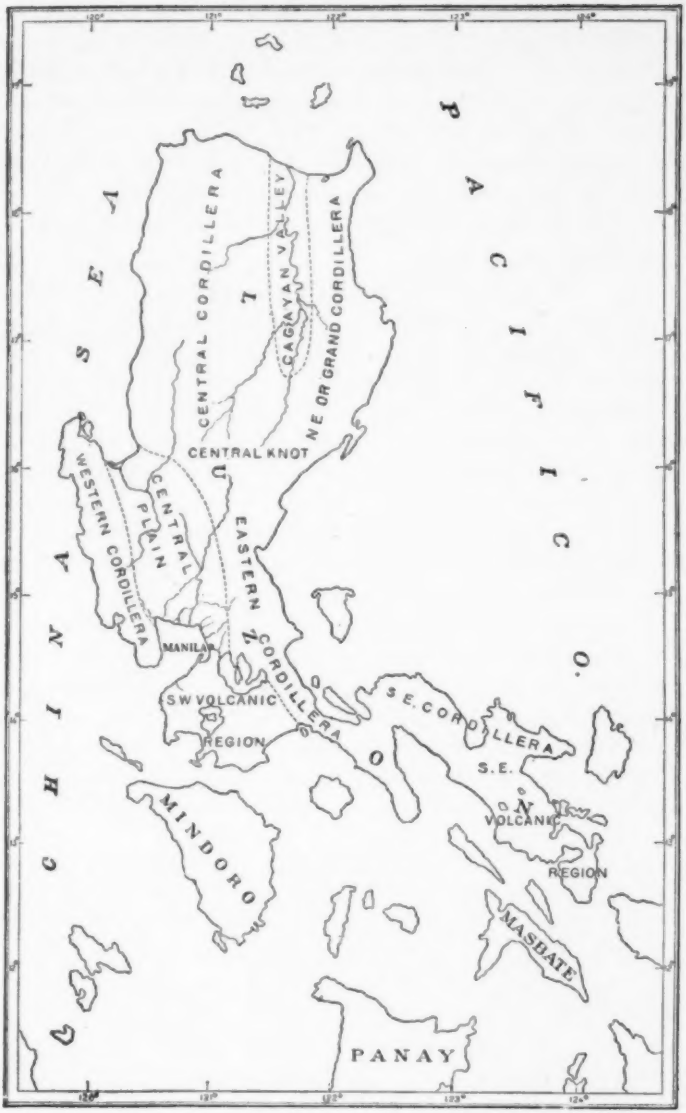


FIG. 1.—Map of Philippine Islands. (After Adams.)

west of Luzon, and the drowned river areas on the Camarines coast on the eastern side. We find extensive settlements on the western side of Luzon, on these coastal plains, the principal tribe being the Ilocanos, the members of which are perhaps the thriftiest and most energetic of all the tribes of the Philippines. These are the only people who produce all their own rice. On the eastern side of Luzon, the settlements are very, very scarce—in fact but little is known, or of the people north of Baler, except that they are not numerous.

THE CENTRAL PLAIN OF LUZON

The principal interior plain of Luzon is known as the Great Central Plain (Fig. 1) and is the chief place of settlement in the Philippine Islands. It is roughly, 120 miles long by 70 wide, stretching from Manila Bay on the south to Lingayen Gulf on the north. On the west, it is bounded by the Zambales Mountains, and on the east, by the Eastern Cordillera. This plain was probably the site of an ancient arm of the sea—a fact that has been called attention to by a number of geologists, among them Adams[1] who has drawn a hypothetical map of the Tertiary geography of the central portion of Luzon.

Composition.—In the northern and western portions this plain is largely composed of alluvial material, as shown by well-sections at Lingayen. In the southeastern part it is largely made up of pyroclastics, as can be seen in railroad and river cuts and numerous well-sections. That this pyroclastic material extended to a considerable depth is shown by the following well-section at Pasay near Manila:

SECTION OF WELL AT PASAY, RIZAL PROV., LUZON, P.I.

0	to	18	ft.	soil, sand, and seashells
18	"	83	"	gray and yellow silt with pebbles, shells, and calcareous concretions
83	"	87	"	fine to coarse basaltic pebbles and tuff
87	"	113	"	yellow-gray sand, some clay, fragments of soft tuff
113	"	160	"	yellow-gray tuff
160	"	180	"	yellow sand and tuff, small basaltic pebbles

[1] G. I. Adams, "Geological Reconnaissance of Southwestern Luzon," *Phil. Jour. Sci.*, V, No. 2.

180 to 463 ft. light, yellow-gray tuff, partially with basaltic pebbles
463 " 483 " fine dark sand, some clear grains, tuff, basaltic pebbles
483 " 546 " fine grained tuff, light gray
546 " 570 " dark sand, some clear grains
570 " 594 " tuff, with small basaltic pebbles
594 " 634 " yellow clay with small basaltic pebbles
634 " 690 " dark sand
690 " 713 " fine gray tuff
713 " 743 " basaltic pebbles and fragments of tuff

Physiographic features.—At first glance, the most striking physiographic features of this plain are: (1) the drainage system; in the north the rivers flow to the north and in the south to the south; this is accounted for by warping; (2) the single extinct volcanic cone of Arayat, standing isolated in the center of this great flat; (3) the two large swamps and one lake located in the eastern part; (4) and the vast delta region of the Pampanga River which bounds Manila Bay on the north.

Farther along in this paper, I shall draw some conclusions regarding the human response to the physiographic and geologic conditions, showing how these features have controlled the human settlements, the intermingling of various tribes, and such like questions.

THE ALBAY PLAIN

We shall pass now to the second great interior plain, which is known as the Albay Plain (Southeastern Luzon). This plain is about as long as the one we have been considering, but is much narrower. It extends from Legaspi to San Miguel Bay. It is an old coastal plain, on the outer margin of which a volcanic cluster has been built up since this plain rose from the sea. The main drainage of this plain is to the north by way of the Bicol River. There are two or three small lakes which are little more than swamp-areas along the course of this river. To the west of this plain, the rocks are sedimentary, while to the east, as I have already said, they are recent extrusives. The material of this plain is largely made up of volcanic ash, bowlders, bombs, lapilli, and tuff. This region is the principal hemp region of the Philippine Islands, and I believe that the peculiar composition of this volcanic soil is largely responsible for this.

THE INTERMEDIATE UPLANDS

All of the territory which is not coastal plain or central plain, and which is not above 5,000 feet in elevation, I shall designate as the Intermediate Uplands. Most of the highlands of Luzon will come in this category. Topographically it consists of the foothills and the sloping flanks of the high Cordilleras. The rocks may be of all classes, but the chief formations are the folded Tertiary sediments, limestones, sandstones, and shales, with the coal-measures, which slope away from the central ranges. Also the lower, and generally worn-down, volcanic stocks will be comprised under this heading.

The population in the Intermediate Uplands consists largely of the less progressive types and of more or less recent white settlers, prospectors, etc. In certain parts of Luzon, such as in Batangas and Laguna Provinces, where the underlying formation is a decomposing volcanic material and where the country is not too greatly dissected by streams, there is a fairly prosperous population, but in the uplands of northern Luzon very little advancement can be noted. There are scarcely any roads and there is very little communication between the different communities. The greater dissection of the country by the streams has decreased the area of agricultural land, and unless the mineral resources be developed, the country will always remain comparatively backward. The people who inhabit those sections give very little promise of ever being able to take advantage of the mineral resources as these are usually low grade and refractory.

THE CORDILLERAS

The eastern Cordillera.—The eastern Cordillera has a general north-and-south trend, but is marked by great sinuosities, following pretty closely the east coast of Luzon, so that in its southern extension where it cuts through Ambos Camarines, particularly in the Caramoan Peninsula, it is running almost east and west. Very little is known about the eastern Cordillera and but few prospectors have crossed it. Here and there in the northern part, some adventurous ones, notably Messrs. Heise and Dudley, crossed. Ickis (formerly a mining engineer in this Bureau) made a recon-

naissance from Laguna de Bay to Infanta, and Pratt and Adams have been on the Caramoan Peninsula. A few boats have skirted the east coast of Luzon, but very fragmentary observations have been brought back.

It is needless to say that we know very little about the elevation of this Cordillera, except that it is much lower than the central Cordillera, and in several places, to which I shall refer later, the range is quite low.

We know practically nothing about the formations in the northern part of this range. Ferguson found a volcanic peak, Mount Kawa, near the northernmost point. Ickis has made a cross-section from Tanay to Infanta (Fig. 5), showing closely folded sediments, diorite, and andesites. Adams and Pratt found considerable andesite in the central part of the range in Ambos Camarines.

If we examine the map showing the distribution of civilized and wild peoples, published in the second volume of the first Philippine Census, 1903, we note that the whole eastern Cordillera from Cape Engano to Casiguran Bay, and, except for two or three spots as far down as Infanta, is inhabited by Negritos. Then, continuing along the coast almost to San Miguel Bay, there is a long strip pretty well taken up by Tagalogs. Then, in the Caramoan Peninsula, the Negritos are found again with some Bicols. At any rate the population is very scanty.

Beginning at the north, we find several well-defined passes through this range, and these passes are the location of trails leading from the interior to the coast. The first one runs from the headwaters of the Ilagan River eastward to Palanan Bay. Then about 50 miles south is another one leading across from the headwaters of the Cagayan River to Casiguran Bay. Only a few miles south of that is another which runs across from Cabanatuan to Baler. The next important pass is following the Chico River from Penaranda to Dingalen Bay. Farther south is the route followed by Ickis from Tanay on Laguna de Bay to Infanta. Another one extends from Pagsanjan to Mauban. Then from Lucena to Atimonan. In Ambos Camarines, this Cordillera splits up into two: one following as already described, the Caramoan Peninsula; the other stretch-

ing in a southeasterly direction down into Sorsogon, and this is crossed in two very important places—the first trail leads from Nueva Caceres to Pasacao, and the second from Albay to Pilar. These passes have been most important in the settlement of certain parts of the east coast. There has always been very little trading along the east coast and, by examining the map alluded to before, there are seen to be several isolated spots occupied by Tagalogs and it is my opinion that these Tagalogs have come across the mountains rather than by the longer way of the sea. From what we know of the history of the United States, mountains are great control-factors in the distribution of people. I have but to call attention to the Cumberland Gap leading from the Appalachian valleys into the "blue grass" regions of Kentucky and Tennessee. For a certain period in the history of the United States, practically the entire flow of the population was through this pass.

The central Cordillera.—The central Cordillera begins about the latitude of Lingayen Gulf and extends north to the northernmost point of Luzon. It is not a single range but consists of two or three parallel ranges. The eastern Cordillera and the central Cordillera start from what Adams calls the "central knot" which is the Caraballo Sur in northern Nueva Ecija. The principal range of this central Cordillera is the Polis Range about 25 miles east of Cervantes. In this range is Mount Polis or Amuyao, which is probably the highest peak in Luzon; Mount Data, which is 7,366 feet high, is another high peak in this Cordillera, and Mount Pulog east of the Agno River is also one of the highest points in the Philippine Islands (Fig. 2). On a recent trip into the northern country, I made a boiling-point observation on a peak 45 miles north of Baguio and found the elevation to be 8,236 feet, and there were a half-dozen peaks around me which were much higher. This Cordillera extends, as I have said, to the north coast, and keeps its high elevation practically throughout the whole extent. It is a region of great rainfall and steep slopes—much greater slopes than the material will stand on, so that landslides are of exceedingly frequent occurrence. The vegetation is very scanty, and practically the only forest tree is the pine (*P. insularis*).

The formations are largely igneous, diorite in the bottom of the

FIG. 2.—Topography in Cordillera Central of Luzon

canyon, and andesites on the upper slopes. There are no active volcanoes in this region but there are several extinct craters, and great areas of volcanic tuff. Around Baguio, the summer capital, there is a great deal of this material.

The population of this Cordillera is almost entirely made up of Igorots with the closely related tribes: Apayaos, Ifugaos, Ilongots, who are very scattered, and comparatively backward people, except in their knowledge of agriculture and irrigation. The Igorots of Lapanto practice the art of copper smelting (which was probably taught them by the Chinese) and with considerable success. The country is almost entirely without roads, but there are a great many Igorot trails which do not take any advantage whatever of the topography. The government, however, is building a horse trail which practically follows the backbone of the Cordillera for many hundred kilometers. It is proposed, in time, to make an automobile road out of this. Such a road will be of great benefit to the country and, already, there is a better feeling between these northern tribes and between them and the Philippine government.

As I said before, the Igorots take very little advantage of the topography; however there are several well-defined routes of travel; the principal one being the trail from Bontoc to Tuguegarao, from San Fernando to Baguio by the Naguilian trail and from Candon to Cervantes by way of Tiela Pass. From Tagudin to Cervantes and from Vigan across to Solano by way of the Abra and Chico rivers and then from Laoag across to the Abulog River by the Worcester trail. There is considerable travel by way of these routes, the passes being taken advantage of by the Ilocanos to go up into the Igorot country to trade. The Igorots, however, do not go down to the coast very much, and when they do, go usually for plunder or to buy dogs, which is one of their principal articles of diet. I do not know to what extent the Igorots use these passes. From my own knowledge of them it seems to make very little difference to them whether the road follows an easy grade or goes up and down hill; in fact they often take an up-and-down hill trail in preference to one on the level.

The western Cordillera.—The western Cordillera is generally known as the Zambales Range, extending from Olongapo north into Pangasinan Province. Another part of this range consists of a cluster of volcanic stocks in the Province of Bataan. This range of mountains is not by any means a continuous one—there being a few isolated high peaks—but in the main the range is not very elevated. The highest point in this range is Mount Pinatubo. This has never been accurately measured, but is in the neighborhood of 6,000 feet. Very little geological work has been done in this Cordillera. Von Drasche has done some work in the neighborhood of Iba, and Fanning has touched it in a few points in the neighborhood of Agno and Alaminos in Pangasinan, and I have been on the second highest peak of Pinatubo, about 5,500 feet; and also on one of the high peaks of Mount Mariveles, which is also about 5,000 feet high.

In general, the rocks of this range are volcanic extrusives, andesites, with marls and shales on the flanks. The Cinco Picos Range, however, on the western side of Subig Bay, consists of a totally different rock from that found on the east side, being a dense pyroxenite.[1] There are no active volcanoes along this line,[2] and the old volcanic stocks are pretty well eroded.

There is a considerable stretch of alluvial running from Subig northwest to San Narciso. This stretch of country here is very dry in certain seasons, and owing to the composition of the soil the water sinks in rapidly and the whole appearance of the country is very much like that of the desert in the western part of the United States—particularly on the western slope of Pinatubo. For a

[1] The effect of the geology upon geodetic calculations was very effectively demonstrated recently in this part of Luzon. A considerable discrepancy between the astronomically determined points and the trigonometric stations near Olongapo was found to exist. The small Cinco Picos Range, which consists of pyroxenite, lies to the west of the stations and the great andesitic mass of the Zambales to the eastward. The observers expected the plumb bob to be deflected in an easterly direction owing to the main mountain mass being to the east, but the deflection was in the opposite direction toward the smaller mass. Not until an examination disclosed the denser rock in the Cinco Picos (to the west) could the discrepancy be explained.

[2] It was reported by Mr. Snyder of the Bureau of Lands that smoke was seen issuing from the top of one of these peaks.

more detailed description of this country, the reader is referred to Vol. IV, sec. A, No. 1, p. 19 of *The Philippine Journal of Science;* "Contributions to the Physiography of the Philippine Islands," IV, W. D. Smith.

We have, more or less, general notes on the population of this region but our main source of information comes from Reed who wrote quite extensively on the Negritos of Zambales. These people are pretty much the same as the Negritos of other parts of the Island, and make up a very much scattered and nomadic tribe.

The principal pass across this region is from O'Donnell in the Central Plain, to Iba. The government has built a road, within recent years, between these points.

There is another well-defined trail from Mangatarem across to Infanta at the southern end of Dasol Bay.

There is also a good road from Alaminos to San Isidro, and in the southern part there is a telegraph line from Olongapo to Dinalupijan. With the exceptions of the use by the natives and occasional expeditions of U.S. Marines, this trail is very little used.

The northern Zambales are not covered with a particularly heavy growth of timber; in fact, many parts, like Pinatubo are quite bare up to about 5,000 feet—the last 1,000 feet being covered with a dense mossy forest; this is due to the excessive moisture from the clouds which continually hang about the summits. In Bataan Province, the vegetation is very dense and the forests possess considerable commercial value. The Cinco Picos Range, however, is almost bare.

The southeastern volcanic cluster.—In northern Ambos Camarines, as I have already mentioned, the Cordillera bifurcates: one fork running through the Caramoan Peninsula, and the other following the west coast. Between these two in what was originally a more or less level plain, there has been built up a cluster of volcanic cones more or less dissected by erosion. However, there is one very perfect cone, Mount Mayon, which is probably the most perfect volcanic cone in the world. This is the highest of the group, and is only a short distance from Legaspi. What must have been a larger cone at one time, is now represented by Mount Isarog; but the symmetry of this has been destroyed by one side of the

mountain sliding out, so that there is a great gap in the crater on one side. In spite of the great size of these mountains and the deep canyons on their slopes, they are of very recent origin. Recently Adams, who made a trip through that country, has compiled all of the various reports in a very interesting and able discussion in his "Geological Reconnaissance of Southeastern Luzon," which is found in Vol. VI, No. 6, *Philippine Journal of Science*. Of all the travelers through this district, Martin, the government photographer, is the only one who has brought back good photographic records.

In 1909, Mr. Martin and a Franciscan Father from the town of Tobaco, made an ascent of Mount Mayon and secured fine pictures of the crater and of the country as seen from the crater. The most interesting point in connection with Mount Mayon, is, that the curve of its slope is so perfect that it can be represented by the formula for the sine curve:

$$\frac{4}{c} = \frac{e^{-z/c} - z/c}{2}$$

when $c = 8.6$ mm.

This was worked out by Dr. G. F. Becker of the U.S. Geological Survey, who made a geological reconnaissance of that region in 1901.

An extensive population is found at the foot of these mountains, but in the higher parts there are only a few Negritos.

This district is one of the finest in the Islands, from a scenic point of view, as well as agriculturally, and occasionally, as in 1900, very spectacular eruptions take place from Mount Mayon.

Further south in Sorsogon is another large dissected volcanic stock called Mount Bulusan. This is very much like Mount Isarog in general appearance.

THE RIVERS

There is a host of rivers of all sizes in Luzon. I shall, however, refer to eleven only. The largest river is the Cagayan in the northern part of the island, the shortest, perhaps, is the Pasig, but from a human standpoint, the Pasig is by far the most important of all.

The Cagayan.—This river rises at about latitude 16°, and empties at Aparri, N. 18° 30′. Apart from local sinuosities it is a remarkably straight river, leading one to believe that it must follow some

structural line. This river is navigable up to Ilagan, and along its banks are located the principal tobacco fields of the Islands. At Aparri considerable difficulty is experienced from the formation of bars crossing the river mouth. The insular government is spending considerable money in keeping this channel open. This stream flows in a very wide, level plain and the soil is remarkably rich.

The Pampanga.—The second largest river of Luzon is the Pampanga. This river rises in the Caraballo Sur Mountains or in the "Central Knot," and flows somewhat west of south and debouches into Manila Bay, by means of a myriad of channels. This river is navigable for a long distance into the interior, and is one of the principal highways of commerce in Luzon.

The Agno.—The Agno river rises on the slopes of Mount Data in north central Luzon, and flows due south until it reaches the Pangasinan Plain where it turns sharply to the northwest and empties into Lingayen Gulf. This river is navigable for a short distance from its mouth, but in the mountain district is simply a roaring torrent washing along big bowlders, and is not at all navigable. This river overflowed its banks twice during 1911, flooding a large section of Pangasinan Province.

The Abra.—The Abra rises also on the slopes of Mount Data, then turns abruptly to the north, flowing for 40 miles or more until it gets to the town of Dolores, where it makes another very sharp bend and flows southwest, emptying into the ocean near Vigan. This river throughout a great deal of its extent is located in a deep gorge. Very little is known of the geology along its course.

The Bicol River.—The Bicol River where it rises due west of Daraga is known as the Kinali River. Thence it flows northwest along the Albay central plain, through one lake (Lake Bato) and a large swamp, finally emptying into San Miguel Bay. This river is navigable almost to Bato Lake. It very frequently overflows, and for this reason, the district through which it flows is one of the principal rice districts of the Islands.

The Angat River.—The Angat River is referred to here more on account of its length, than for any other reason. It rises in the Eastern Cordillera, flowing with considerable sinuosity westward, and empties into the Kingwa River which also flows across the

Bulacan Delta into Manila Bay. This river is not navigable to any great extent, but at Norzagaray the river has some falls where considerable power could be obtained.

The Bued River.—The next river in point of size is the Bued River, which, while much shorter than the Agno, flows in the same direction, and is only mentioned here, because of its connection with the famous Benguet Road. This river is probably responsible for more damage to the works of man than any other river in Luzon.

During the summer of 1911, it was the scene of a very destructive flood, which was due to a cloudburst, near Baguio. Thirty-seven inches of rain fell in twenty-four hours in Baguio. The larger part of this water flowed into the Bued River Canyon, and at the lower end, there occurred a great landslide which dammed the stream to a height of 60 feet. When this dam broke, a large portion of the lower end of the Benguet Road was washed out into the Pangasinan Plain. This road has suffered repeatedly from these floods.

The Pasig River.—The Pasig is a very short river, 15 miles, very deep and of moderate width, and is the outlet of Laguna de Bay. It is important mainly because of the great volume of commerce which travels along it, and for the fact that the capital of the Archipelago is situated at its mouth. This river is tidal in its lower section, about up to Fort McKinley. From here on to the lake, it is much narrower and quite shallow in places. The river has a very treacherous current.

The Paracale River.—The Paracale River is mentioned here not on account of its size, but because it is distinguished by two very important features. The most important is that it is probably the richest river of all, there having been discovered considerable stretches of rich gold placers along its course. From a physiographic point of view, it is interesting, because, in its lower portion, this river is a drowned river. It has long been known that the Camarines coast is subsiding.

THE LAKES AND SWAMPS

The true lakes in Luzon are first and foremost, Laguna de Bay; second, Taal Lake; third, Laguna de Canaren, Bato and Buhi, while the following, Paway, Cagayan, Pamplona, Mangabol, and Candaba are merely great swampy areas, whose size changes with the seasons.

FIG. 3.—Taal Lake; Taal Volcano on low island in right background

In his study of the Southwestern Luzon region, Adams has discussed the two first-named bodies.[1]

Laguna de Bay is a heart-shaped body of water with two prongs of land projecting into it from the north side. It lies a short distance southeast of Manila, and is separated from Manila Bay by about 6 miles of land. Its dimensions are 25 by 28 miles. It is fairly shallow. The height above sea-level varies between 0.9 and 4.3 feet.

Taal Lake.—The second largest lake in Luzon is Taal Lake or Laguna de Bombon (Fig. 3). This has generally been regarded as a crater lake by such writers as von Drasche and Becker, but Adams who has perhaps given more time and study to it than any other, attributes the origin of the lake to peripheral faulting. My own opinion is that the lake has originated through (1) peripheral faulting, (2) explosion of a former and much larger volcano than now exists there, and (3) subsequent collapse of the crater area (Fig. 4).

For details about this lake and volcano, I shall merely refer the reader to the three most exhaustive articles on this subject.[2]

THE HUMAN RESPONSE TO PHYSIOGRAPHIC CONDITIONS

The relationship between man's work and physiography, has long been emphasized by many writers. Although this relationship has often been over-estimated,

[1] G. I. Adams, "Geologic Reconnaissance of Southwestern Luzon," *Philippine Journal of Science*, V, No. 2.

[2] G. I. Adams, *op. cit.*; W. E. Pratt, "Eruption of Taal Volcano," *Philippine Journal of Science*, VI, No. 2; D. C. Worcester, in *National Geographic Magazine*, 1912.

FIG. 4.—Photograph of model of Taal Crater as it was before the great eruption of January, 1911.

many things having been explained as due to the topography of the country that have really been very little affected by it, still it is certain that physiography is a factor of considerable importance. We know as yet too little about the wild tribes of the Philippines and too little of the topography of the country, in some parts, to make it safe to dogmatize much at this time. However, a few general statements may be made, which are to be taken as tentative, and (like a railroad schedule) are subject to change.

If we examine again the census map alluded to above, we note that there are certain dominant tribes in Luzon. In the north central region, the part occupied by the Cordillera Central, the dominant tribe is Igorot. In only one place does he come down to the coast, and that is where the Cordillera itself reaches the coast.

Next to this tribe, and almost completely hemming it in, are the Ilocanos, a rapidly increasing tribe and probably the most virile of all the tribes in the Philippines. It occupies the Coastal Plain, but has already gained a foothold in the Central Plain. Since the opening up of new roads and trails in the mountainous area, he has begun to wedge his way into the territory of the Igorot.

Occupying the "Central Knot" and adjacent mountainous country, we find the Ilongots.

The Negrito has been pushed back into the more or less unknown and inaccessible tracts, such as the Zambales and the southern Cordilleras.

Surrounding Manila Bay and extending down into Tayabas, we find the Tagalog. It is yet too early to state definitely, but it would seem that the Tagalog is becoming more and more restricted.

The southeastern peninsula is occupied almost exclusively by the Bicol, but here again in the almost inaccessible parts are to be found the Negritos.

Around Lingayen Gulf there is a small area occupied by the sub-tribe known as Pangasinans.

A recent writer on ethnological subjects says, that if a Bontoc were dressed in the clothes of the Tagalog and the Tagalog (un-) dressed like the Bontoc, it would be very difficult to note the difference. This is my own opinion about these people and I believe that the differences are very superficial. As soon as the

railroad and the school have had a chance to work on these people and mix them up, the tribal characteristics will largely disappear. At the present time it seems that the following characteristics may be noted with reference to the different tribes:

The Ilocano lives on the Coastal Plain and spends a great deal of his time at sea, as the Coastal Plain is too narrow to furnish all of the food necessary. He is, because of this life a nomadic individual and has therefore been able to penetrate farther into the other districts in Luzon. I expect to see this tribe, in time, dominate Luzon.

The Igorot is a much stockier man than the Ilocano, and shows, in his build, the effect of his hill-climbing life. Due to the mountain barriers, he has been kept more isolated and has to spend more time getting his food, and therefore is more of a stay-at-home. Many of the Igorots will not leave their own communities, being afraid to go from one town to another. The government is dispelling this vague fear of the Igorot, and many barbarous customs, such as head-hunting, are fast becoming obsolete. It is believed that the physiography of the country has had a direct and very important effect upon the people. Traveling in that country is a serious matter, and they will not take the trail, unless they are very hungry or some other inducement is offered.

The Negrito is very evidently a vanishing tribe. The government by its paternalism may for a time postpone the extinction of these people, but the arrest in their development seems to have been so complete that it is a question whether they can ever recover, or whether it would be of any particular value to the human race for them to recover. The writer has been among these people, and while he has seen some signs of an organized life, it is a hand-to-mouth existence, and they are often little better than animals. They are exceedingly shy and one may travel for days at a time through their country without seeing anyone.

The Tagalogs are the most advanced in western civilization, of all the tribes of Luzon, and a glance at the map will show how they have clustered about the capital of the Archipelago. Physically not much can be said of them. They do not produce very much of their own food, being mainly engaged in the more sedentary pro-

fessions. Whether the new form of education being introduced into the Philippine Islands will regenerate them, remains to be seen. It is a notable thing that they occupy only about one-third of the Central Plain of Luzon. The Ilocano, Pangasinan, and the Pampangan are fast crowding them back toward Manila. Some might argue that physiographical conditions are responsible for the political dominance of the Tagalog. But this connection is only an indirect one. The chief Spanish settlement of the Archipelago has always been Manila. Of course, Manila's situation depended upon physiographic features, and the Tagalogs happened to be where the Spaniards first settled, and in that way they have obtained their political pre-eminence, but it has been rather through the relationship to the Spaniard, than to the fact that he is living along the Pasig River and around Manila Bay.

The Bicol is a hard-working and very peace-loving individual, and is a man of the fields. It is not believed, however, that he will materially increase his present range.

Another tribe which appears to be peculiarly influenced in its habitat by physiographic conditions, is the Cagayanese. He is confined exclusively to the Cagayan Valley and the Batanes and Babyanes Islands directly north of Luzon.

We also note another feature in connection with the distribution of tribes: that the densely forested areas are occupied by the Negritos, the forests furnishing additional means of concealment.

What future changes will take place in the distribution of these people can only be conjectured. It is my opinion, that the Tagalog will follow new railroads and new highways. The Ilocano will probably dominate all of the lowlands, because he is a great rice grower. The Bicol will probably remain stationary, and the great stretch of country now covered by the Igorot will be criss-crossed by the paths of the Ilocano. All through this population will be found scattered, the Chinaman, as in all the countries of the Orient. He is not a producer, however, but occupies in the Malay world the same place as the Jew in the Western World. Outside of the large cities, the Chinaman controls the trade. As the government has placed severe restrictions upon the Chinaman, he is not now a very important factor. He affects the population to a certain extent,

by intermarriage with the natives, but the Chinaman as a Chinaman need not be considered further in this article.

GEOLOGY

GENERAL CONSIDERATIONS

If we examine the general geological map of the Island of Luzon, we distinguish in the southern part, a rough lining up of formations into belts or long strips having a northwest–southeast trend.

First, at the extreme southeast, there is a zone of metamorphic rocks beginning on the small island of Rapu-rapu and extending northward through Ambos Camarines in the vicinity of Mambulao. Their continuation will undoubtedly be picked up some day along the east coast of Luzon, farther north.

Next, to the westward, is a belt of recent volcanics. In this belt, are the well-known cones of Bulsan, Mayon, Iriga, Isarog, and the pretty well worn-down stock of Bagacay.

Third, the narrow Albay Plain.

Fourth, a broader belt of folded sediments in the western part of the Sorsogan peninsula, and constituting practically the whole of Tayabas peninsula. This belt continues up into Central Luzon, where it becomes partially concealed by later volcanic flows.

Fifth, another volcanic zone which takes in Taal, Talim and Arayat, in the eastern portion of the Central Plain.

Sixth, the plain belt, beginning with the Cavite Plain and the Central Plain, extending north to Lingayan gulf.

Seventh, the line of andesite stocks constituting the Zambales.

Eighth and westernmost, the very basic and dense rocks of the Cinco Picos range, just west of Subig Bay. This last is really almost insignificant in area, but very important as has already been mentioned.

In the northern part, we cannot, as yet, make such clean-cut separations, owing largely to our ignorance. However, a rude parallelism of belts can be made out.

Having considered the distribution of formations geographically, let us now turn to a consideration of the stratigraphic sequence; this is best shown by the tabular scheme in Table 1.

The absence of older formations than the Tertiary from this column may be explained by one or more facts, namely:

TABLE I

TABULATED SCHEME OF STRATIGRAPHY

Period	Formation	Type Locality	Distribution	Economic deposit	Characteristic fossil
Recent	Coral reefs	Cebu	Along much of the Philippine coast line	Building stone and lime	
	Littoral deposits	Sangley Point		Sand	
	Volcanic tuff	Vicinity of Manila	Southern Luzon, Ilocos Norte	"Guadalupe" stone for building	Leaves, probably belong to *Euphorbiaceae*
	Basalt and andesite flows	Mount Arayat and Mount Apo			
Unconformity					
Pleistocene and Pliocene	Raised coral reefs	Cebu, west coast	Cebu, northwestern Luzon		*Hindsia dijki* Mart.
	Marls	Ilocos Norte	Samar, Agusan River		
	Eruptives	Mount Mariveles	Mindanao, Luzon, etc.		
Unconformity					
Miocene	Limestone—upper	Cebu		Burned for lime, very pure	Shells very similar to recent forms; chiefly coral reefs
Unconformity	Andesite flows	Do	Cebu, Masbate, etc.	Gold, silver, manganese, lead	
Miocene	Limestone—middle	Do	Cebu, central Luzon, southwestern Luzon, north Mindanao, east Mindanao, Romblon	Romblon marble, Montalban limestone	*Lepidocyclina insulae-natalis* Chap.; *Lithothamnium ramosissimum* Reuss. *Cyloclypaeus communis*; *Orbitolites*, etc.
	Sandstone	Batan Island		Oil in Tayabas and Cebu	
	Shale	Do		Coal deposits, Cebu, Batan, Polillo, Masbate Mindanao, Luzon, etc.	*Arcas*, *Callianassa dijki* Mart.; *Vicarya callosa* Jenk.
Oligocene	Limestone—lower	Cebu, Batan Island			*Nummulites niasi* Verb.
Age uncertain, probably Tertiary	Crystalline schists, granite, gneisses	Camarines	Camarines, Ilocos Norte, Cebu, Zamboanga Peninsula, Romblon Island	Gold, mica, talc, apatite, hematite, magnetite	
	Iron formation	Bulacan			
Unconformity (?)					
	Radiolarian cherts	Ilocos Norte			Sponge spicules and fragments of Radiolarian tests
	Quartz porphyry	Lepanto	Central and northern Luzon	Copper ores	
Pre-Tertiary (?)	Diorites	Benguet	Northern Luzon, Leyte, Panay	Gold tellurium, silver	
	Gabbros	Leyte	Leyte, Mindanao, etc.	Serpentine and asbestos	
	Pyroxenite	Ilocos Norte	Ilocos Norte, Zambales Mountains, Batan Island		
	Peridotite	Near Olongapo			

1. Very little exploration has been carried on in the dissected areas of northern Luzon, where we would expect to find the older formations.

2. The Philippine Islands are situated at the outer edge of the Continental shelf, where the sediments are all recent and the older rocks would naturally be very deeply buried.

3. Erosion has not as yet progressed very far, owing to the comparatively short period that the archipelago has been above the sea.

Below are given two sections across Luzon at different latitudes (Fig. 5. Infanta to Tanay [Ickis], and Fig. 6. North Central Luzon [Eveland]).

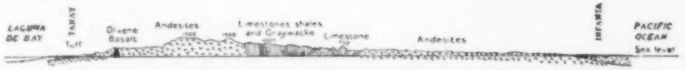


FIG. 5.—Section from Laguna de Bay to the Pacific. (After Ickis.)

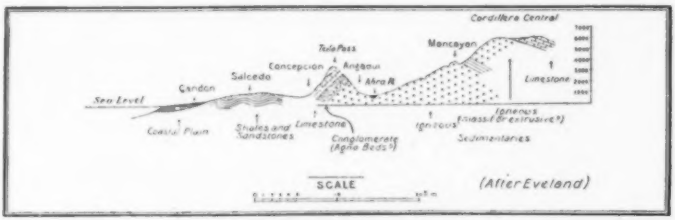


FIG. 6.—Section across North Central Luzon. (Eveland.)

THE IGNEOUS COMPLEX

By the igneous complex, we mean all those igneous rocks overlaid by the tertiary sediments, some of these are diorites, some andesite and diorite intrusions and others are granites. They are naturally encountered over larger areas in northern Luzon, where erosion has been at work longer and more vigorously. The central Cordillera then is the principal habitat, if we may use the term in this connection, of this class of rocks. Farther south, particularly in the vicinity of Manila, these rocks are deeply buried and only appear in isolated localities as in Ambos Camarines, the Loboo Mountains of Batangas, etc.

Diorite, quartz diorites, metadiorites, granites, gabbros are all found in Luzon. Diorite is the commonest deep-seated rock.

There is complete gradation from this rock into andesite, the difference between the two being chiefly one of depth and hence rate of cooling of the original magna.

As Professor Iddings has worked over most of the rocks in our Philippine collection, I shall refer the reader to his descriptions of these rocks.[1]

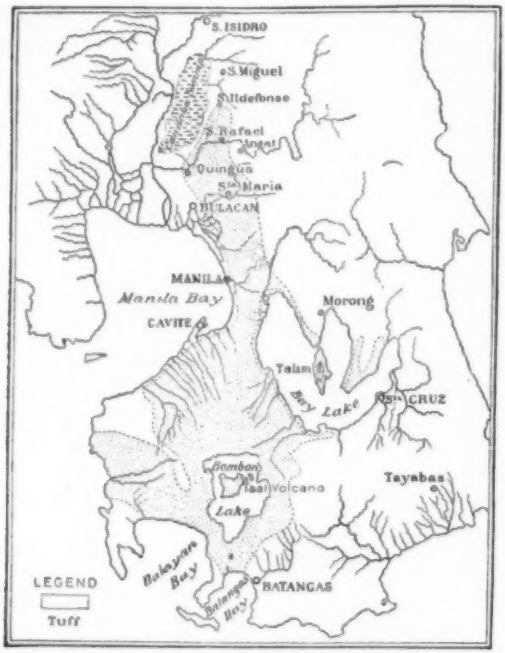


FIG. 7.—Map of Southwestern Luzon. (After Centeno.)

The extrusives.—As far as we now know, the andesites form the more or less worn-down volcanic stocks, and the basalts represent distinctly later flows. The andesites and basalts are generally fairly uniform, but we have besides, vast areas of volcanic agglomerates grading from a formation made up of large blocks more or less angular and somewhat scoriaceous, to a rather fine-grained tuff.

[1] J. P. Iddings, "Petrography of Some Igneous Rocks of the Philippines," *Phil. Jour. Sci.*, V, No. 2, 155.

Iddings, Oebbeke, and the writer have described specimens of these rocks from various parts of the Islands, but Iddings is the only one who has attempted anything like a systematic study of them, with a view of drawing conclusions concerning petrographic provinces, correlation, etc. He found that pyroxene andesites with hypersthene and augite both present predominate, next hornblende-pyroxene andesites, and third, hornblende andesites without pyroxenes, and last, a few with biotite in addition to the minerals already named.

There is a complete gradation from the andesites to the basalts. Some of the latter are extremely rich in olivine.

Dacites have been found in a few localities, Corregidor Island at the entrance to Manila Bay being the type locality.

The greatest distribution of agglomerates and tuffs is to be found in the region of Laguna de Bay and over a large part of Batangas Province (Fig. 7). The agglomerates are especially well shown in a deep and very picturesque gorge at Pagsanjan, Laguna, and from there all the way to Mount Banajao, one finds nothing but volcanic agglomerate with patches of tuff here and there. This tuff and agglomerate have been more particularly discussed by Adams in the article already referred to.

THE METAMORPHIC ROCKS

Metamorphic rocks have been found in Ilocos Norte, in Ambos Camarines and in Benguet, probably in many other parts they will be found when more exploration has been carried on.

In Ilocos Norte, we have actinolite and mica schists, bordering a granulite dike, in Benguet marble, due to diorite intrusion, in Ambos Camarines gneissic granite and schistose diorite.

The rocks of the volcanic mountains are by far the most widely distributed[1] of all the rocks in Southern Luzon, and possibly in the Island as a whole. The country surrounding Manila and southwestern Luzon is the principal home of these rocks. The chief centers are Arayat, Taal and Banahao, Mariveles, and the southwestern volcanic cluster. The principal rocks are andesites with later flows of basalt.

[1] For general distribution of the major formations the reader is referred to the map in *Regionale Geologie* (Steinmann in Bonn), VI, pt. 5, by Warren D. Smith.

THE TERTIARY SEDIMENTS

We have found in Luzon, so far, no sediments known with certainty to be older than the Tertiary. In Ambos Camarines, there is a brecciated sandstone, and a shale, which some have thought to be older, but fossil evidence is entirely lacking. In Ilocos Norte, on the Baruyan River, I found some outcrops of a very red brecciated jasper, which may represent a Jurassic formation. I made thin sections of this rock, and, while I made out no definite fossil forms, Dr. Karl Martin of the Reichsmuseum in Leyden, who examined them, said he could distinguish the remains of sponge spicules, and fragments of radiolarians, and he was of the opinion that the rock was very similar to specimens he had found in the Moluccas and which he had called Jurassic. These are exceptional and isolated cases. The main bulk of the marine sediments of Luzon are Tertiary sandstones, shales, and limestones. The sandstone is usually a fine to coarse-grained grey rock which is very impure, having, as a rule, more feldspar and ferromagnesian than quartz fragments. Just how thick it is, we have never been able to determine, through lack of good sections. It probably varies from 60 to 325 feet in thickness. The shales are bluish-black to light yellow, very fine-grained, and generally low in silica. There is every gradation between the sandstone and the shale. The shales lie over and above the coal seams at nearly all the outcrops. How thick these are, we do not know exactly. They usually are very thin-bedded and are not very consolidated. Above the sandstones we find a hard, white, crystalline limestone which contains abundant remains of foraminifera—the principal genus being orbitoides. Below, I insert Professor Douvillé's classification of the Philippine Tertiary, as worked up from material which I furnished him in 1908. This table (Table II) may fairly well represent the stratigraphy of Luzon. The uppermost limestone is noteworthy for its purity, as it has been changed very little since its formation in the sea. Coral remains are very abundant in many parts of it, in fact at an elevation of nearly 5,000 feet in Benguet we find a fossil coral reef containing fragments of many species of coral, most of which are now growing in the China Sea.

TABLE II

(AFTER DOUVILLÉ)

		Philippines			Borneo	
	c	Upper limestone with *small* Lepidocyclines	*Lep. c.f. Verbeeki miogypsina*	H	Burdigalien	Miocene
2	*b*	Sandstone and shale	*Clycoclypeus communis, Orbitolites alveolinella Miogypsina*	G F	Aquitanien	
	a	Middle limestone with *large* lepidocyclines	*Lep. insulae-natalis, formosa, richthofeni*	E		
1		Lower limestone with nummulites, Coal Measures	*Nummulites niasi Verb., Amphistegina c.f. Niasi, Lepidocyclina*	D	Stampien	Upper Oligocene

RECENT FORMATIONS

Under the recent formations, I shall take up the following: (*a*) Piedmont deposits; (*b*) coral reefs; (*c*) pyroclastics; (*d*) placers; (*e*) laterite, and products of weathering.

In a region of such tremendous rainfall, such as we have in the Philippine Islands (45 inches in twenty-four hours, recorded at the Baguio Observatory, Mountain Province, Luzon, July, 1911), probably nowhere exceeded save possibly at Simla in India, it is natural to expect great erosion in the high levels, and a deposition of the eroded material in great volume at the foot of the mountains. Such deposits can be found in Pangasinan Province, where the Agno and Bued River flow out onto the Central Plain, and along the western coast in the Ilocano Provinces. A great deal of the coastal plain of Ilocos Norte and Ilocos Sur is built up by this wash material, brought down by the short and rapid mountain streams. A great deal of this deposit consists of huge bowlders which are of considerable annoyance to farmers, and are serious obstacles to gold dredging, but with these bowlders comes down great quantities of finer material, which must play a great part in enriching the soil.

Coral reefs.—An examination of the coast and geodetic charts now issued for the coast-line of Luzon, show that there are great stretches of coral reefs. They are very important not only from the point of view of navigation, but they represent the foundation for the lateral growth of the island-mass. My own observations on the west coast of Luzon reveal the fact that much of that coast is now rising, and as the coral reefs grow up to a limiting plain—the

surface of the water—they naturally present, when elevated, a more or less flat platform upon which the rivers deposit their loads and in that way build up new land. On the east coast, it is not so easy to see this growth, as throughout much of its extent, the coast is sinking: witness the drowned river-mouths of the Paracale and other important rivers.

The Pyroclastics.—The present eruptions and those of the Pleistocene have generally been marked by great quantities of ash and rarely by out-pourings of lava. A great deal of this material happened to fall into the sea or other bodies of water and was subjected to a sorting process and as a result, we get the great beds of tuff so well developed adjacent to Manila. These beds alternate with marine sands showing rapidly changing conditions.

This tuff has been experimented with and found to be of practical value in the making of a variety of sandlime brick.

The greatest development of this, as has already been mentioned, is around Laguna de Bay, near Manila.

Placers.—On the east coast of Luzon in the vicinity of Paracale, Ambos Camarines, there is a considerable development of rich placer ground. The country is notable for the great number of "stringers," rich in gold, most of which are too small to work on an extensive scale, but where they have been eroded and the detritus has become concentrated in pockets in some of the "drowned," valleys on that coast, some remarkably rich ground has resulted. Gold and native copper as well as galena and sphalerite are found in them.

In the streams near Manila, principally the Mariquina, some platinum has been found. Along the Bued River also are promising placers.

Laterite, etc.—Naturally the action of weathering in the tropics is very important and very pronounced, but on the higher lands, it is not always so evident, because the tremendous rainfall quickly removes any unusual accumulation of material.

The great development of ferro-magnesian minerals in the igneous rocks, results in an extensive accumulation of iron rich soil on the lower slopes, and this is so often like the deposit known as laterite, as to merit special mention as a distinct formation.

Much that passes as laterite in the East is undoubtedly merely a product of weathering of rocks, in place, though it is recognized that there is more than one mode of origin.

ECONOMIC

COAL

No workable coal seams have been yet opened upon the Island of Luzon, though in Spanish days, some pretense was made to work some seams at Bacon in Sorsogón Province. At this place, the seams appear to be continuations of those on Batan Island. The Spanish engineers had opened up these seams with several hundred meters of galleries.

Coal has been found at several other places on the mainland, in the sub-province of Bontoc Ilocos Sur, Rizal, Bulacan and Tayabas, but either in too small seams, or in unfavorable localities.

However, on two islands, so near the Luzon coast as to be practically a part of that island, namely, Polillo and Batan, workable coal seams have been prospected and partially developed for some time.

Batan Island.—The East Batan mine, which is located on the East end of Batan Island, consists of several hundred feet of underground workings on a seam of coal about five feet thick. The main entry to this mine is about 1,500 feet long, and runs in on the coal seam, at an angle of 42° from the direction of dip. The dip of this seam varies between 10° and 13°. The coal is a subbituminous coal with lignite qualities.

The government has erected at this mine large coal pockets and the coal is being used in the island steamers. Some development work was carried on on the western end of this Island by the United States army in former years, but it has now been abandoned.

Polillo Island.—On the eastern side of Polillo Island which lies in turn on the eastern coast of Luzon, there are four, probably five, seams of a very fair grade of coal. Two of these, possibly only one, will be found to be advantageously worked. These seams are dipping at a moderate angle toward the coast, but near the center of the Island where the coal measures abut sharply against the igneous rock, the seams are highly inclined, and in some cases vertical.

The development work is now in progress in that district. This coal is of somewhat better grade than the Batan coal. Coal has been found of a poor quality in a number of other places on the Island of Luzon, namely in Cagayan Valley, in North Central Luzon and in the sub-province of Abra, but no development work has been carried on there.

IRON

As the next most important mineral resource, we shall consider iron. This mineral in small quantities is wide spread. It is usually found associated with the crystalline rocks of the eastern Cordillera. It has been found in noteworthy quantities, in two districts, near Angat Bulacan and on a small island in Mambulao Bay, Ambos Camarines. It is quite probable that there is a fairly continuous belt of this mineral following the Cordillera between its two points. Magnetic Surveys to determine this, are now in progress by the division of mines, Bureau of Science.

At Angat, the iron deposits appear to be of considerable extent, but diamond drilling will be necessary to prove this. The ore is a very hard bluish hematite, which is found in the crystalline rocks, and is probably a segregation due to the alteration of chalcopyrite, and other iron-bearing minerals in these rocks. The natives here have mined and smelted this ore in a crude way for over a hundred years. No flux is used and charcoal is the reducing agent. The most successful of these iron workers is a native woman, Dona Maria Fernando, who sells about 15,000 plow shares and points a year, throughout the neighboring provinces.

Several engineers have examined the deposit in Mambulao Bay and it is the general opinion that there is a commercial quantity at that point, which can be worked from sea-level.

OIL

Petroleum has been discovered in seeps at several points in the Bundoc Peninsula in Tayabas Province (see reports by Adams, Eddingfield and others in the Mineral Resources of the Philippine Islands) and one well has been sunk to a depth of 140 feet. As yet, there is no commercial production and none can be hoped for, till deeper wells are bored. The whole country-side in that region has

been plastered with claims, by speculators and others, totally ignorant of the business or who have no money to carry on the necessary operations properly.

With a view to opening up this field, the government has begun triangulation in the district and later, this will be followed by topographical and geological surveys.

The oil is very light, having a paraffin base. It has a beautiful, clear, cherry color. An analysis is as follows:

ANALYSIS[1] OF OIL FROM WELL, NEAR THE VIGO RIVER

Specific gravity of oil at 15°5 C	0.845
Initial boiling point	80 c.
First fraction, light oils, 70°–150° C	27.0 %
Second fraction, burning oil, 150°–300°	56.75 %
Residuum above 300° C. by diff.	16.25 %

The formations here are Tertiary sandstone, shales, and limestones, flexed into a broad gentle anticline, with minor flexures, faults, etc., and is more or less intruded by igneous rocks.

Oil has been reported from other localities in Luzon, the chief one being near Aliminos in Pangasinan Province, but examination by members of the Division of Mines revealed no trace of oil. The formations there are, however, favorable for the accumulation of oil.

GOLD

In the very earliest records wherein the Island of Luzon is mentioned, there is also a reference to gold. When Magellan reached Cebu in 1521, he heard accounts of gold in that part of Luzon, now known as Ambos Camarines.

The natives of that province have a very pretty legend about how on a certain time, a golden carabao comes out at night from one of the mountains and passes under the sea to a neighboring mountain and how the gold deposits are in some way, connected with that carabao.

For centuries, the natives have panned for gold in their crude way, not unlike the methods employed by all primitive peoples, and they have even gone so far as to construct a crude and very limited

[1] Analysis by G. F. Richmond, Bureau of Science.

dredge, capable of handling a half-ton of gravel and sand in a day. Not only did the Tagalogs, but all the tribes including the wild Igorots, pan gold and from nearly every stream in the island. I have never yet found a stream which did not carry some gold. This gold, won by the natives, usually finds its way into the hands of the Chinese traders, and consequently it is difficult to get even an estimate of how much is recovered annually, but I believe that one thousand ounces a month is a very conservative estimate.

In the early eighties of this century, there were scores of arrastres in operation in Ambos Camarines; but hardly a single one can now be seen. This method, with which all mining men are familiar and hence need not be described here, was introduced by Spaniards from Mexico, probably over two hundred years ago.

At the present time, there are only one or two arrastres working in the district.

Several attempts at mining on a large scale were made, prior to the American occupation, but all were futile. But with the inrush of American prospectors and renewed vigor and new hope in the country, the outlook for the mining industry became very bright.

The first modern stamp mill of any size was erected on the Benguet consolidated property and began operating in 1906, and in 1907, the first large dredge (New Zealand model) was placed on the Paracale River. There are now two dredges at work, one building and a fourth projected.

The mills have not been so successful, due to a variety of causes, chiefly inadequate capital and poor management. The lodes are of many kinds. In Benguet, they are usually quartz fissure veins in andesite, while some contact deposits between the sediments and andesite and diorite have been noted. The gangue is predominately quartz with or without calcite, manganese oxide, and rhodochrosite. The gold is in some veins free, but is usually found in the pyrite in a finely divided condition, so much so that the best method of treatment will consist of crushing in cyanide with stamps and fine grinding in tube mills.

In Paracale in Ambos Camarines, there is much more free gold and a large number of the veins are "stringers," which are very

tantalizing and have been the ruin of more than one over-enthusiastic miner. In these veins the gangue is mainly a cellular quartz. There is also enough zinc and lead to complicate the process of treating these ores. Very little manganese is to be seen in these veins and the striking fact to be noted here is this, that this is the best placer district so far found in the whole archipelago.

COPPER

Copper has been found in the form of arsenates and sulphides in the Mancayan-Suyoc district of the Mountain Province, Luzon and the Camarines. The best known deposit is that in the Mancayan-Suyoc district. Eveland[1] writes the following concerning this deposit:

> In view of the fact that the entire region, with the exception of the one ore body of the Mancayan mine, is in an early stage of development, it is impracticable to treat the ore deposits in detail. It seems to be fairly conclusive, however, that the general type of vein in the district is a narrow quartz lead, carrying metallic sulphides, in some cases of copper, and generally with gold associated in a free state. These veins are in the Mancayan diorite which underlies the entire district. With the advent of the "trachyte" flow, metamorphic changes have taken place and the nature of the country rock is altered to a considerable degree.

Recent development work has shown this deposit to be rather in the nature of a stockwork, and it appears to me to be more extensive than was first thought to be the case.

[1] A. J. Eveland, *Bulletin No. 4*, Min. Bur. Manila (1905). For further data regarding the mineral resources of the Philippines the reader is referred to the annual bulletin *Mineral Resources of the Philippines*, issued by the Division of Mines, Bureau of Science, Manila, P.I.

PRELIMINARY NOTES ON SOME IGNEOUS ROCKS OF JAPAN*[1]

S. KÔZU
Imperial University, Sendai, Japan

COMENDITE

This remarkable rock is found as blocks in a small stream running into the Bay of Iibi, a small village on the northeastern coast of Dōgo. The environs of the village consist mainly of schistose granitic rock and its porphyries, in association with rhyolites. Though the exposure of the comendite was not observed by the writer and its geological occurrence cannot be stated at present, it seems highly probable that the rock is a differentiated and effusive form of the same magma from which the above-mentioned rocks were derived.

Megascopically, the rock is light gray with a bluish tone and exhibits a distinct wavy flow structure, produced by the arrangement of feldspar crystals and lighter-colored crystalline bands, and has a tendency to platy parting under the hammer. Numerous phenocrysts are quartz and feldspar. The quartz is conspicuous, with rounded outline, and varies in diameter from 1 mm. to 3 mm. The feldspar is glassy, fairly well defined, and prismatic or tabular, from 1 mm. to 5 mm. in length, the prevailing length being 2 mm. Megascopic phenocrysts of colored minerals are rare. The groundmass shows a certain diversity of texture, some parts being aphanitic and compact, and some parts more crystalline and lighter in color. This property produces the fluxion structure already mentioned.

Microscopically, the constituent minerals are quartz, alkali-feldspar, arfvedsonite, barkevikite, aegirite, aegirite-augite, titaniferous iron, magnetite, and apatite. The conspicuous pheno-

* Published by permission of the Director of the Imperial Geological Survey of Japan.

[1] A continuation of Paper VI, on "Quartz-Syenite and Comendite from the Oki Islands," published in the issue of this Journal for October–November, 1912.

crysts are quartz and feldspar, the latter being more abundant. Besides these, there are present bluish-green and deep reddish-brown ferromagnesian minerals belonging to the pyroxene and amphibole groups. These are fewer and smaller than the colorless phenocrysts. The groundmass is strongly marked with flow structure, due to both the diversity of crystallinity and the arrangement of constituent minerals. The greater part shows a microfelsitic texture, essentially composed of quartz and feldspar, through which are scattered numerous small ragged shreds or mosslike patches of aegirite and aegirite-augite, associated with minute grains of magnetite. A microspherulitic intergrowth is also seen. Through this fine groundmass are coarser crystalline bands, mainly composed of feldspar and quartz with subordinate green pyroxene, developed in a lenticular form. The mode of development of these minerals exhibits some peculiarities. The minerals occurring in the marginal part of the lenticular area are arranged perpendicular to its outline, but those in the inner part show a microgranitic or micropegmatitic arrangement.

The quartz phenocrysts are mostly subhedral, sometimes anhedral, with diameters varying from 0.05 mm. to 3 mm., but euhedral forms are also seen. The mineral contains several kinds of inclusions. Glass inclusion with or without a gas bubble is not rare. They are commonly bounded by crystal planes. There are abundant inclusions of groundmass material, showing irregular forms. Aegirite groups are also inclosed.

The feldspars are wholly alkalic, and almost all of them are possibly soda-bearing potash varieties, though a few crystals appear to be sanidine. The phenocrysts occur in two shapes, tabular or columnar, and are commonly subhedral. In some instances, the outline is strongly rounded and curved, and is deeply invaded by the groundmass. Some crystals have a regular shape, fairly well inclosed by crystallographic faces. The twinning observed is wholly Carlsbad, and no microcline structure is noticeable. The feldspar material is entirely fresh and is plainly marked by the cracks characteristic of sanidine. The plane of the optic axes appears to be perpendicular to (010). The acute optic angle ($2E$), measured on three thin sections, is $56° 34'$, $50° 16'$, and nearly

zero. The optical character is negative. Inclusions are common. The most abundant are of groundmass material, as is the case with

FIG. 3

the quartz phenocrysts. Quartz is frequently inclosed, and pyroxene and glass are also seen.

The ferromagnesian minerals belonging to pyroxene and amphibole groups are arfvedsonite, barkevikite, aegirite, and aegirite-augite. The amphiboles occur as phenocrysts, and the pyroxenes both as phenocrysts and in the groundmass. The phenocrysts of these minerals are usually found in association. Barkevikite occurs irregularly intergrown with the arfvedsonite on the one hand, and with the aegirite and aegirite-augite on the other. Their shapes are elongated or short prismoid, but their outlines are irregular and ragged. No cross-section was found in ten thin slices made for the purpose of determining the cross-section. So the determination of the optical orientation of the minerals was difficult. The aegirite-augite is distinguishable from the aegirite by its higher birefringence and larger extinction angle, reaching $c \wedge X = 37°$. From the aegirite, the arfvedsonite is distinguishable by the extinction angle and its direction, compared with those of the barkevikite associated with them. The aegirite extinguishes at a small angle or nearly zero in β, in which the barkevikite extinguishes also, while the arfvedsonite extinguishes in $-\beta$. On a longitudinal section, the extinction of the barkevikite was measured as $c \wedge Z = 2°$, and the arfvedsonite showed $c \wedge X = 15°$ in concurrent direction. Some crystals are strongly decomposed and are completely altered into a yellowish-brown substance. There are a few minutes rods to be identified as aenigmatite in the groundmass. They are deep brown or almost opaque.

Chemical character.—A chemical analysis of the rock, made by K. Yokoyama in the chemical laboratory of the Survey, compares fairly well with those of the comendites from other localities, described by different authors. It shows well its characteristic properties: high alkalies and nearly equal amounts of soda and potash, low lime and magnesia, fairly high iron oxides, and low alumina in proportion to alkalies and silica.

The analysis of the rock from the Oki Islands is given under column A in the following table, and is compared with those of the comendites from Comende, Sardinia (B)[1], and Iṣkagan Bay, East Siberia (C).[2] They resemble one another very closely, though

[1] H. Rosenbusch, *Elemente der Gesteinslehre*, 3. Auflage, p. 332.

[2] H. S. Washington, *American Journal of Science*, XIII (1902), 180.

the rock from the Oki Islands differs from the others in lower silica and in total and relative amounts of iron oxides.

	A	B	C
SiO_2	72.21	74.76	75.44
Al_2O_3	11.20	11.60	11.98
Fe_2O_3	2.25	3.50	0.88
FeO	2.66	0.19	1.02
MgO	0.08	0.18	0.10
CaO	0.27	0.07	0.33
Na_2O	4.29	4.35	4.06
K_2O	4.81	4.92	5.01
H_2O+	1.45*	0.64	0.68
H_2O-	....	....	0.13
TiO_2	0.44	Trace	Trace
P_2O_5	0.10	Trace	....
MnO	0.10	Trace	Trace
Total	99.89	100.21	99.63

* Loss on ignition.

A. Comendite from Iibi, Dôgo, Oki. K. Yokoyama analyst.
B. Comendite from Comende, Sardinia. M. Dittrich analyst.
C. Comendite from Iskagan Bay, East Siberia. H. S. Washington, analyst.

Norms of these rocks are given in the following table:

	A	B	C
Quartz	28.3	31.6	31.9
Orthoclase	28.4	28.9	30.0
Albite	30.9	32.0	33.0
Acmite	4.6	4.2	0.9
Diopside	0.5	....	....
Hypersthene	3.4	0.5	2.1
Magnetite	0.9	0.7	0.9
Hematite	....	1.6	....
Ilmenite	0.9	....	....
Apatite	0.3	....	....

From the above table, it will be seen that the rock from the Oki Islands is closer to that of Comende than that of Iskagan Bay and is richer in femic minerals than the other two.

The ratios of the Oki rock are as follows:

$$\frac{Sal}{Fem} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 8.26$$

$$\frac{Q}{F} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 0.48$$

$$\frac{K_2O' + Na_2O'}{CaO'} \quad \infty$$

$$\frac{K_2O}{Na_2O} \quad 0.86$$

By the *Quantitative System*, the rock may be classified under the name liparose, in which the other two comendites from Comende and Iskagan Bay belong also.

THE QUIZZYHOTA LACCOLITE

E. H. L. SCHWARZ
Rhodes University College, Grahamstown, South Africa

EARLY REFERENCES

The first reference to this remarkable mountain that I can find is contained in a description of Kaffraria by the Rev. Francis Fleming:[1]

But perhaps the most surprising and gigantic of these singular precipices, as yet known in Kaffraria, is that which rises on the south bank of the Great Kei River, about seven miles from the old military post of Fort Warden and lying fifty miles north of King Williamstown. It forms one side of a singular shaped mountain, the Quizzyhota.[2] The top is a long table-land of some miles in length, but contracted to about one or perhaps less in width. The extremities of the mountain and of the krantz which forms the whole north side of it and which is thickly covered with aloes, euphorbias and orchids, rise suddenly at angles of nearly 45°; the surrounding country stretching out into low undulating ground thinly dotted over with straggling mimosas and spec-boom, *Portulacaria afra*, gives an abrupt and most singular appearance to this object. On the southern side, which is thickly covered with large and thick bush, the hill descends with rather a more gradual slope and so affords an easy retreat for the Kaffirs.

For the purpose of visiting this singular locality a party of six officers left their quarters during the war of 1846. (Theal gives 13th November, 1847.) One of the number, however, feeling indisposed, left their party a short distance from the camp and returned home and so escaped the untimely end to which the other five poor fellows came. These unfortunate and deeply lamented officers were: Major William Leinster York Baker, Lieutenant Clarevaulx Faunt, Ensign William Burnop (Adjutant) and Doctor Neil Stewart Campbell of the 73rd Regiment, and Doctor R. J. Locke of the 7th Dragoon Guards. The author who visited the spot in person to superintend (by request) the removal of the bodies to King Williamstown, made every enquiry while there respecting them and their death scene. One Kaffir was shown to him who displayed a wound on his right side which he said he had received from one of the gentlemen

[1] *Kaffraria and Its Inhabitants*, London, Simpkin, Marshall & Co. (1854), 39.

[2] *Quizzyhota* is a Kaffir word meaning "the place where one warms one's hands." The name is particularly applicable to the mountain as the middle slopes consist of bare faces of dolerite which, exposed throughout the day to the sun, absorb the heat and become intensely hot.

(probably Major Baker) whom he described as fighting most gallantly to the last and only killed by overpowering numbers. The author has also every reason to conclude that all were killed there and then and that no previous torture of any kind was attempted by the Kaffirs.

Two days had passed before their bodies were discovered and brought to Sir George Berkeley's camp then pitched on the banks of the Komgha stream, a small tributary of the Kei, about ten miles from the spot where they fell. Here they were hastily interred in one grave, but in the month of August, 1850, only a few months before the present Kaffir outbreak, the bodies were fortu-

FIG. 1.—Etanga Valley from railway. The Quizzyhota, showing the horizontal Karroo rocks above and the bare faces of dolerite below.

nately removed and reinterred in an unmolested and shortly to be consecrated grave beneath the western tower of Trinity Church, now in course of erection at King.

The woodcut of the scene accompanying Mr. Fleming's account is taken from about the thirty-second milestone on the newly constructed Amabele–Butterworth railway; this, and the fact that the Quizzyhota faces northwest, clearly identify the actual scene of the slaughter. Locally the abrupt mountain opposite the Quizzyhota and separated from it by the gorge of the Etanga,[1] which forms a much more prominent landmark from the level of the river, is

[1] *Etanga* is a Kaffir word meaning a "place where the cows are kept." The best cows are kraaled round the huts, but the surplus are sent out to some sequestered place, usually inclosed, as this particular valley is, by inaccessible cliffs, so that by merely fencing the narrow opening the cattle are prevented from wandering.

called Mordenaars Kop or the Murderer's Hill, but this is clearly incorrect.

DESCRIPTION OF THE QUIZZYHOTA LACCOLITE

The laccolite extends some 3 miles along the Kei River and it can be traced for some 6 or 8 miles into the plateau on which the village of Komgha stands. The plateau is some 2,000 feet high; the village which lies in a slight hollow is 2,114 feet above sea-level; the bottom of the cliff is 500 feet, so that the height of the vertical

FIG. 2.—The western end of the Quizzyhota laccolite, showing the vertical faces of the dolerite on the north and the undisturbed Karroo rocks in front.

face of the laccolite is 1,500 feet. The laccolite ends along the river in a vertical face which, however, is seen only in the western end and then for only a part, as the undisturbed horizontal sedimentary beds form three-fourths of height of the hill. Down stream, on the east of the Etanga Valley, the dolerite is exposed nearly to the level of the river bed, but there is always a little foot of sediments between the dolerite and the river; here unfortunately weathering has degraded the vertical face of dolerite to a slope of about 30° covered with gigantic bowlders, and it is impossible, therefore, to give a photograph showing the entire face. The rock

readily splits up along joints when exposed on the surface, and even the fresh face on the west, where it is exposed above the sedimentary beds, has scaled to a depth of some 10 feet or so; and the slopes below are covered with scree formed of the fallen blocks.

Along the Etanga Valley the dolerite comes toward the Kei River with a covering of 100 feet of sediments, then just below the farmhouse, on top, the dolerite breaks through to a higher horizon; at the western end there remains a covering of sedimentary

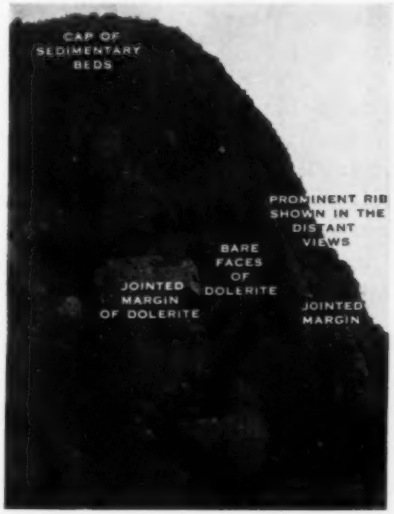

CAP OF SEDIMENTARY BEDS
PROMINENT RIB SHOWN IN THE DISTANT VIEWS
BARE FACES OF DOLERITE
JOINTED MARGIN OF DOLERITE
JOINTED MARGIN

FIG. 3.—Western end of the Quizzyhota laccolite.

beds of about 30 feet thick, but on the Quizzyhota Hill the dolerite apparently reaches the summit. The line of demarkation where the dolerite impinges on the sedimentary rocks is exposed with extraordinary clearness on the krantz. The length of the laccolite along the river is cut twice by short valleys; the easternmost is the Etanga Valley, which is a deep fjord-like gorge that runs into the dolerite, doubtless along lines of original fracture which have been worked out by weathering. The valley forks into two branches about half a mile from the entrance. One of the branches

runs south and ends in a cul-de-sac surrounded by bare faces of dolerite; the other runs west. The bottom of the valley rises very gently and is about a hundred yards wide. It is surrounded everywhere by the dolerite; the new railway skirts the edge of the southern branch, and the view as one looks down into this cleft from the carriage window is most remarkable. The streams flowing down into the Kei from the escarpment of the plateau are very steeply graded, but here is a valley which begins at the head with a vertical wall 1,000 feet deep.

The laccolite is about three miles long from east to west, the exposed vertical side facing north, but there is a low-lying expansion of about 100 feet above the level of the river which is exposed in a cutting near the zig-zag of the railway, and this would add another mile to the length along the river. The faces of the main mass are quite vertical toward the river which comes almost due south to the laccolite, abuts against it, and follows its northern edge to the east. The sedimentary rocks are for the most part cleared away from the northern side. On the downstream end, above the hotel and road-bridge, the dolerite has been exposed for a long while and there is only a steep slope rising at an angle of 30°, studded with gigantic bowlders of dolerite, but for the rest grassy, with sparse mimosa trees. About two miles up the river is the Etanga Valley. On the west the dolerite rises in a magnificent vertical wall, capped with horizontal beds of sandstone for some 30 feet. On the outside of the vertical face there is a zone of much-jointed dolerite rising in pinnacles on either side of a sort of window of sedimentary rocks through which the vertical face appears. The pinnacles are the jointed outer margin of the laccolite. The dolerite to the west of this plunges into the sedimentary beds which form the walls of the valley of the Great Kei River lying almost at right angles to the northern face of the laccolite. In other words, the laccolite has barred the way of the river which flows at its foot, and the weathering that has allowed a small amount of sedimentary beds to remain plastered, as it were, on to the face of the laccolite on the west, has cleared all these away down stream on the east. In the same way the sedimentary beds form half the height of the hill on the west of the Etanga Valley, between the dolerite and the river, so that

at first sight it would appear that the actual base of the laccolite was exposed, but farther down stream the dolerite descends to the bed of the river. The sedimentary rocks in the bed of the river, though quite close to the dolerite, are unaltered and undisturbed.

The top of the laccolite spreads out to the south beneath the thin covering of sedimentary beds, perhaps reaching the village of Komgha which lies to the west-southwest about 10 miles from the bridge in a straight line (18 by railway). Three miles from the village, however, the railway skirts a shallow valley on the plateau which is covered with rich black soil, very different from the light sandy soil derived from the weathering of the sedimentary beds, which is good only for pasture lands; here, however, every inch is cultivated. This is the first exposure of dolerite which one can definitely connect with the Quizzyhota laccolite. The dolerite continues along the railway for 2 miles, then runs over the sedimentary covering for half a mile, and then again for about 200 yards is carried over the dolerite. Beyond, the railway cuttings are in the sedimentary beds forming a thin undisturbed covering to the laccolite, till the Etanga Valley is reached 2 miles farther on. Here the railway crosses the road at No. 6 railway cottage, and the plunge into the valley of the Kei begins. For a little distance the railway is cut in the eastern slope of the laccolite, which is here intensely weathered, the square jointed blocks having broken down into a brown sand, while in their centers there remain, in many cases, rounded blocks of quite unaltered rock. The blocks exposed in a similar position on the western end facing the river are jointed in the same way, but there is no evidence of the spheroidal weathering nor of the intense alteration. It appears that the intense crumbling is a consequence of the covering of sour soil which yields organic acids in large quantities and thus supplies a powerful solvent for the iron combined in the ferro-magnesian minerals. The finest example of the spheroidal weathering about here is in the great laccolite which lies 3 miles from Amabele Junction and which is exposed along the railway to within a few miles of Komgha village (27 miles from Amabele). Here the jointing is horizontal and vertical and every tenth block, more or less, has a solid unaltered core of grey dolerite. The weathered material can be dug with a spade and is

used extensively as fine gravel. The spheroidal weathering is noticed only on the outer margin of the laccolites. From the top of the Etanga Valley to the river level there is a drop of 1,500 feet; Komgha lies on the plateau at 2,114 feet above sea-level, and

FIG. 4.—The Quizzyhota Mountain, showing the dolerite breaking up through the Karroo sedimentary beds. Looking east, i.e., down stream.

Sihota,[1] the station just on the Transkeian side of the bridge, at 560 feet. Sihota lies some 50 feet above the river. This drop of 1,500 feet is accomplished by the railway in 10 miles, or less than half that in a straight line, and just before entering the zig-zag by which the train reaches the level of the river there is a small expo-

[1] *Sihota* is a Kaffir word meaning an "ant-bear."

sure of dolerite in the cutting, which may belong to the main laccolite or may be a horizontal dyke proceeding from it, or may be quite an independent body; farther away there is an exposure of dolerite in the small valley crossed by the railway but the relationships of this and dolerite in the cutting are uncertain.

In the Amabele-Komgha laccolite the mass rears its head above the general level of the plateau which belongs to the 2,500-feet plateau[1] but which has been degraded by surface weathering some 300 to 400 feet. The Amabele-Komgha laccolite was below the level of the original plateau, although now its bald head is exposed; the Quizzyhota laccolite, on the other hand, is only just beginning to appear on the plateau, being for the most part hidden by the sedimentary beds.

THE SEDIMENTARY ROCKS INTRUDED BY THE QUIZZYHOTA LACCOLITE

The Sedimentary Beds cannot be placed in any definite scheme as yet. They consist of whitish or light grey-blue sandstones, fairly loose in grain, interbedded with blue shales, weathering yellow. They correspond to the Karroo Beds as exposed in the Free State and Transvaal and to which Dr. Molengraaff gave the name of "High Veld Series." Farther east, at Idutywa, the whiteness of the sandstones becomes more pronounced and the shales become brilliantly colored with red, purple, and blue tints, but the ordinary blue shales occur as well. Dr. Rogers and myself gave these beds the name of the "Idutywa Beds."[2] Subsequently Mr. Du Toit described the same beds from Queenstown and Burghersdorp districts as the "Burghersdorp Beds."[3] There seems no necessity to reduplicate names, and the term "Idutywa Beds" will be used here; eventually, if the connection is established with the Transvaal rocks, Molengraaff's term will have to be adopted. The suggestion to call them the *Cynognathus* beds, from the occurrence in them of this remarkable Theriodont reptile, does not appeal to

[1] E. H. L. Schwarz, "Coast Ledges in the South-West of Cape Colony," *Q.J.G.S.*, LXII (1906), 70.

[2] A. W. Rogers and E. H. L. Schwarz, "General Survey of the Rocks in the Southern Part of the Transkei and Pondoland, Including a Description of the Cretaceous Rocks of Eastern Pondoland." *Ann. Rept., Geol. Comm., 1901*, Cape Town (1902), 28.

[3] *Ninth Ann. Rept., Geol. Comm. 1904*, Cape Town (1905), 77.

me, because the fossils are extremely rare and localized, whereas the formation can be very clearly recognized by its lithological characters. Where the usual fine-grained blue sandstones of the Beaufort Beds proper give place to the coarser-grained white varieties, one can at once draw a line of division and map the latter as Idutywa Beds.* The Idutywa Beds extend into the Western Karroo north of Laingsburg and far to the north in the Transvaal.

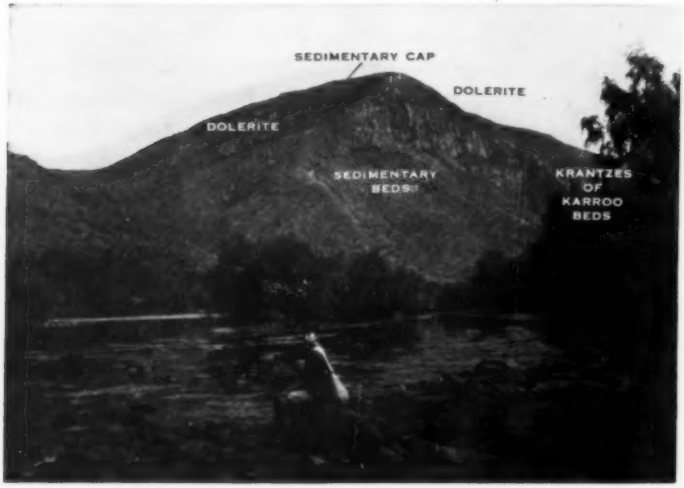


FIG. 5.—Western end of the Quizzyhota laccolite, showing the vertical face of the laccolite on the north and the sedimentary beds, plastered, as it were, onto the face, themselves quite undisturbed.

They once had a wider area of deposition than any other of the divisions of Karroo System.

Toward the middle of the descent of the Kei Hills the white sandstones disappear, and in their place there are the ordinary blue and blue-black shales, weathering olive-brown, which belong to the Beaufort Series. The normal sandstone banks of the formation farther west do not appear, probably because the weathering is so different. Here in the east, the country is a recently dissected plateau covered with grass and scored by deep ravines; in the west

the beds are exposed under arid conditions and the small differences of texture and hardness are very boldly shown on the faces of the kopjes. It may be that these differences are not sufficiently great to cause a separation into sandstones and shales in the sides of the ravines, where there is always a considerable amount of moisture. These beds were called by Dr. Rogers and myself the "Kentani Beds" in the report referred to above, and they were taken to be an

FIG. 6.—Top of laccolite, Mazeppa Bay, Kentani (just west of where the diorite dykes of the Transkei Gap run out to sea at the Koghe River mouth). The bleaching and hardening of the strata are well shown in the fallen blocks, where the bedding planes have become obliterated.

eastern facies of the Beaufort Beds. Dr. Rogers and myself obtained *Oudenodon* remains on the coast of Kentani, and there is an undescribed *Dicynodon* skull from Umtata in the Albany Museum belonging to the same horizon. The specimen was collected by Mr. E. J. Dunn; I submitted it to Mr. Watson, who informed me that the species was of the type found in the lower Beaufort Beds. On the Umkomazan River in Natal Dr. Broom[1]

[1] R. Broom, "Fossil Reptilian Remains from Natal," *Third Report Geological Survey of Natal and Zululand*, London, 1907.

described *Lystrosaurus*, which occurs on a higher horizon, but still within the Beaufort Series proper, so that these beds must occur in a strip running more or less north from East London, where again reptiles of the same horizon occur; but their development is not continuous. In Umsikaba (Flagstaff), in Eastern Pondoland, Dr. Rogers and myself found the Umsikaba Beds (the local facies of the Ecca Beds) directly followed by the Idutywa Beds. At the time, not knowing that the Kentani Beds wedged out, we placed the Idutywa Beds below the *Dicynodon* or Kentani Beds, thinking that they represented the *Pareiasaurus*—zone of the Beaufort Series; this was a natural mistake when working upward in the series, as there is a complete conformity between the Dwyka and Umsikaba (Ecca) Series and the Umsikaba and Idutywa Series. Later, however, working downward, we found the Molteno Beds of the Stormberg System lying directly on the Idutywa Beds.

Western Karroo	Eastern Districts	Pondoland	Transvaal
Idutywa Series	Idutywa Series	Idutywa Series	High Veld Series (Coal Measure Series)
Beaufort Series	Kentani Series	Wanting or only locally developed	Wanting
Ecca Series	Ecca Series	Umsikaba Series	Wanting
Dwyka Series	Dwyka Series	Dwyka Series	Dwyka Series.

PER SALTEM CONFORMITY

Such a conformity as that represented by the Umsikaba Series being followed by the Idutywa Series I will call a *per saltem* conformity. It is due to want of supply of sediment during some lengthened period. The most conspicuous example of it that we have in South Africa is the conformity between the Bokkeveld Series (lowermost Devonian) and the Witteberg Series (Lower Carboniferous), the whole of the Upper and Middle and most of the Lower Devonian being unrepresented. On the supposition that the fossils in South Africa have the same value as time markers as those in the northern hemisphere—which is a debatable point, but one which seems to become more definite as the material accumulates and the study of it advances—this conformity between the Witteberg and Bokkeveld Series is explained by the shore retreating

till detritus from land could no longer reach the particular locality; at the same time, owing to the violence of the currents or the coldness of the sea or for some other cause, the calcareous deposits in the deep ocean did not form, or, if they did form, were dissolved. Then when the sea-floor rose again and the shore advanced, sedimentation began once more, and the new deposits were laid down conformably on the older ones, although a considerable lapse of time had occurred between the two.[1] In the *per saltem* conformity between the Umsikaba and Idutywa Series we have other considerations to take into account. We are dealing with fresh-water deposits. In the Cape Colony proper, that is to say, in the central, south and west portions of the Great Gondwanaland Lake—Lake Union we might call it, as it embraced all the colonies united in the Union of South Africa, whereas the Karroo sediments of Rhodesia and farther north appear to have been deposited under independent sheets of water—the depth was greater and the sedimentation more extensive in the early Karroo times. This portion then filled up and the depression shifted up to the north and east. The hinge of the movement, if we can conceive the lake floors in the two periods as forming two planes meeting along a straight line, would run through Umsikaba (Flagstaff) in Pondoland and the deposits of the earlier depression would then be restricted to irregular arms and bays of the older lake and would form discontinuous pockets, as indeed they appear to do.

THE RELATIONSHIP OF THE DOLERITE TO THE SEDIMENTARY BEDS

It has been necessary to go into a little detail with regard to the sedimentary beds around the great Quizzyhota laccolite, because I seek to prove in the sequel that the dolerites are in part the product of the melting and absorption of the sedimentary beds. I have for many years been looking for a good example to work on, but there have been objections to all of them. The ordinary dykes of the Karroo are of no use, as it is impossible to prove that the space occupied by the igneous rock has been melted out by the dolerite. Immense laccolites occur in the center of the Karroo

[1] E. H. L. Schwarz, "South African Palaeozoic Fossils," *Records Albany Museum*, Vol. I, Grahamstown (1906), 360.

dolerite area in Fraserburg, and one of them furnishes an illustration appearing in Dr. Rogers' *Geology of Cape Colony*,[1] but the contacts are covered. In Burghersdorp, Cradock, and in Cathcart, at Turnstream, along the Great Kei River, there are admirable examples, but only the tops of the great domes appear and no estimate as to the size or shape can be arrived at. A very fine one occurs on the Kentani coast,[2] also exposed only along the extreme top, while the enormous ones of Mount Ayliff, Mount Currie, and others on the Drakensburg Plateau occur in the Molteno Beds and are doubtfully to be ascribed to the same system as the Karroo dolerites. The Quizzyhota laccolite, out of all I have seen in seventeen years' traveling in South Africa, is the best for the purpose I have in hand.

Wherever one finds Karroo sediments, especially those above the *Pareiasaurus* zone, there is usually intrusive dolerite. Again, where the Karroo sediments have been peeled off and the underlying Archaean or Cape system floor is exhibited, there are exceedingly few dykes and those that exist are puny, insignificant stringers as compared to the massive dykes and sills of the Karroo Beds which once lay above them. There is a good example of this to the east and west of Prieska. On the east a loop of the Orange River incloses a peninsula of Karroo shales with a great sill of dolerite. On the west the Griquatown (Pretoria) Beds form the Doornberg Hills, through which runs Prieska's Poort and Keikam's Poort. In both of these gorges thin, nearly vertical, dykes occur, but the main portion of the range is quite devoid of dolerite; yet, looking, to the south where the escarpment of the Karroo Beds begins practically a third of the height of the hills is occupied by dolerite. The occurrence of the dolerite-containing Karroo sediments to the west and south of the Doornberg proves that they were once continuous over the hills.

The question remains: Where did the dolerite come from if there are such feeble channels of supply in the older rocks? Did the Karroo sediments spontaneously melt? I shall seek to prove

[1] 1st ed., 279; 2d ed., 286.

[2] E. H. L. Schwarz, "Origin of the Rand Bankets," *Journal Assoc. for Advancement of Science, S. Africa*, VIII (Cape Town, 1912).

in the sequel that a considerable proportion of the Karroo dolerite is composed of the melted-up sediments, and that the accession of fresh molten material from the deeper portions of the crust was comparatively small in proportion to the amount exhibited on the surface.

THE GREAT KARROO LACCOLITE

All the dolerites of the Karroo—the sills and dykes of the main portion and the laccolites on the east—belong to one and the same system; they together form one immense laccolite of the type known as the "Cedar tree laccolite." The type was first described by Holmes on the La Plata Mountains of Colorado[1] and has since been noted in the gabbro of the Cuillin Hills of Skye,[2] but nothing like the stupendous nature of the Karroo laccolite occurs in other parts of the world. The Karroo laccolite is some 700 miles long by at least 200 miles broad; the great Transvaal laccolite, large as it is, is only 250 miles long. The dolerite sills form generally in the upper portions of the great laccolite, whereas the lumps and expansions forming the subsidiary laccolites, of which the Quizzyhota is one, occur either along the central axis or in the lower portion. In Komgha one is, as it were, in the cellars of the giant structure; the upper stories can be seen to the north in the long table-topped hills of Cathcart. Thence to the north the sills follow each other in countless steps up to the main watershed of the country, which, for a great distance in the west, is a steep escarpment facing south, and generally some 6,000 feet above sea-level, though exceptional heights occur on the north of the Graaff Reinet Division in Compass Berg, 8,500 feet, and Middle Mount, 6,263 feet. East of Compass Berg the main watershed and the central axis of the great laccolite continue in the same direction, but the escarpment curves to the southwest. All these sills dip slightly inward to the north; they are connected by innumerable dykes and often branch and undulate in many remarkable ways. North of the main watershed all the drainage flows into the Orange River, which is held up by the bar across its lower course at the

[1] *Ninth Ann. Rept. U.S. Survey Territories*, Washington, 1877, XLV, Fig. 2.

[2] A. Harker, *Nat. Hist. Igneous Rocks*, 67; "Tertiary Igneous Rocks of Skye," *Mem. Geol. Survey of Glasgow*, Fig. 16, p. 89.

Aughrabies Falls, a little under 2,000 feet above sea-level, and the "kopje veld" of the country south of the main watershed is replaced by wide open flats and the gorges of the rivers by winding, shallow streams of low gradient. Here all the sills dip southward till the old shore line of the Karroo Lake is reached and the older basement

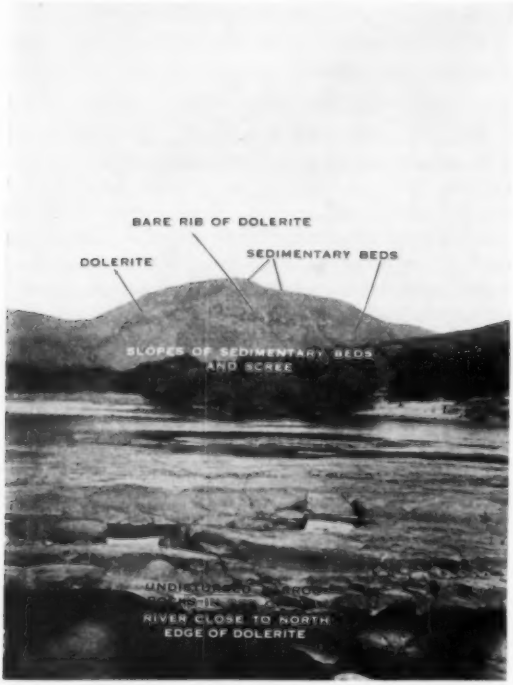

BARE RIB OF DOLERITE
DOLERITE
SEDIMENTARY BEDS
SLOPES OF SEDIMENTARY BEDS AND SCREE
RIVER CLOSE TO NORTH EDGE OF DOLERITE

FIG. 7.—Western end of Quizzyhota laccolite, showing dolerite passing into the Karroo rocks of the Krantzes.

of the Karroo makes its appearance. Besides the main watershed there is another topographical feature to be observed: it is the main escarpment of the Karroo sediments and the dolerite sills which coincide with the main watershed in the west, but diverge from it east of Compass Berg. The escarpment begins on the east

with the Amatolas in King Williamstown Division, thence westward is continued north of Fort Beaufort as the Great Winterberg (highest point 7,800 feet), thence to the Sneeuw Bergen (Compass Berg, 8,500 feet), Koudeveld Bergen, Nieuweveld Bergen (Bulthouders Bank near Beaufort West, 6,270 feet), and finally turns round and faces southwest in the Roggeveld Mountains. Although this great ledge, capped throughout with dolerite, forms the main structural feature in the south of the colony, the rivers take no notice of it east of Compass Berg. The Fish River, especially, starts from the main watershed, although this is situated at a much lower level, and cuts great gorges in the country till it escapes to the lower country beyond the ledge. The main watershed coincides with the escarpment from the Nieuweveld to the Compass Berg; thence the escarpment proceeds in an east-northeasterly direction, whereas the watershed runs northeast by east to Delagoa Bay. The watershed is a consequence of the mode of deposition of the Karroo sediments; when these at last rose above the water-level the thickest deposit was highest and from this insignificant crest the rivers began to run over the featureless plain. The ledge or escarpment, on the other hand, is connected with the folding of the Cape Coastal Mountains, probably in a causal connection, that is to say, the dolerite caused the folding; at any rate the southern edge of the Great Karroo laccolite is parallel to the strike of the coastal mountains. The interval between the escarpment and the folded mountains is from fifty to a hundred miles, but the sills advance considerably in front of the escarpment. Thus, on the extreme east, there are the Amatolas, with the laccolite of Debe Nek in front of it, and dolerite dykes extending to points within 4 miles of the Keiskama River, a distance of 50 miles from the crest of the Amatolas, while the folded mountains lie another 50 miles to the south. However, we must regard the great ledge or escarpment as the main boundary of the laccolite and this runs in a gentle arc, with the ends east and west of each other. The center of the bend corresponds to the alteration of the strike of the Cape folded mountains from east and west, to east-southeast, which alteration occurs in Willowmore, Uniondale and Knysna.

The Karroo Beds south of the folded mountains—at least the

remnants left in the Worcester and Robertson Divisions—are not intruded by dolerite.

The great system of sills and dykes runs out to sea with the Karroo rocks near East London and comes in again with them near St. Johns. From the last place the margin runs north to Pietermaritzburg and Ladysmith, thence across the north of the Orange Free State down the Vaal River to Hope Town, Prieska and Brand Vley, thence through Calvinia to near Karroo Poort in the Ceres Division and from there to Beaufort West.

The Stormberg lavas have nothing to do with the Karroo dolerites which the volcanic chimneys pierce. Dolerite dykes indistinguishable in composition from the Karroo dolerites traverse in turn the lavas of the Drakensburg, but these latter are rather to be regarded as dykes connected with the intrusion of the lava.

The dolerite as a whole is an augite-olivine-plagioclase rock; the varieties with a little quartz in granophyric intergrowth or with mica are quite insignificant. One peculiar glassy dyke with nepheline I obtained in Beaufort West,[1] but otherwise the normal dolerite is of an intensely conservative nature. A diorite often traverses the rocks in the east at Cradock and in Komgha and Kentani.[2] These I shall have to refer to later; they are usually taken to be later injections from a primitive magma which has rid itself of the more basic substances, but I shall endeavor to prove that they are the channels down which the more acid materials absorbed by the dolerite from the country rocks are passed out.

THE PROBLEM OF THE DOLERITE INTRUSIONS

Having now established the relationship of the Quizzyhota laccolite to the dolerites of the Karroo and that of the sedimentary rocks to those forming the main portion of the Karroo, we have to inquire how a great mass of igneous rock can have come to lie within the sedimentary rocks without disturbing their stratification and without notably altering them by thermal metamorphism.

[1] E. H. L. Schwarz, "Geological Survey of the Beaufort West District," *Ann. Rept. Geol. Comm., 1896*, Cape Town (1897), 18.

[2] A. W. Rogers and E. H. L. Schwarz, "General Survey of the Rocks of the Southern Transkei," *Ann. Rept. Geol. Comm., 1901*, Cape Town, 1902; "The Transkei Gap," *Trans. Phil. Soc. S. Africa*, XIV, Cape Town, 1903.

The arguments employed here rely on the theory that igneous magmas are solutions not necessarily at very high temperatures. I shall endeavor to establish the fact that such magmas—which in their injection state may be entirely fluid or may consist more or less of crystals already formed, but yet, as a whole, plastic under pressure with the help of solvent water—have certain properties which cause them to crystallize in one standard type with structure and composition constant, no matter what amount of extraneous rock they may have absorbed. I shall apply to a rock magma and the resulting igneous rock the laws which govern the development of single crystals, such as andalusite, in among rocks of totally different composition, assuming that what holds good for individual crystals, also applies to collections of crystals such as igneous rocks are.

The argument will be, in short, that the original molten or fluid magma works its way up into the rocks near the surface of the earth; the release of pressure sets free a certain equivalent of heat, or more probably chemical activity, which is employed in absorbing the rocks encountered. As portions of the country rock become digested, the bulk of the igneous rock at any one time preponderates over the including fragments, and the mineral composition of the magma asserts itself in that it takes from the fragments it is absorbing such substances as are suitable to the formation of the rock of the type represented by the magma, and unsuitable material is passed downward along the supply dykes. Dykes consolidated before the waste material has been removed are represented in the dolerite dykes of the Rainy Lake region in Canada; for instance, the White-Fish Bay dyke, where the outside is a fine-grained dolerite with 47.8 per cent silica, while the inner side is a quartz hornblende rock with 52.5 per cent silica. These dykes are very wide, 120 to 150 feet. In smaller dykes the up-and-down current appears to have been too rapid for the consolidation to catch the two before the completion of the process. Nevertheless, the composite dykes of Arran are of the same nature, although of different origin. The evidence for this argument afforded by the Quizzyhota laccolite will be given in the sequel; it is necessary first to outline the evidence afforded by the development of single crystals such as anda-

lusite and to show how closely the phenomena exhibited by the larger masses, the igneous dykes and laccolites, are presented by the individual crystals.

THE DEVELOPMENT OF ANDALUSITE CRYSTALS

The development of crystals of andalusite, chiastolite, cordierite, and staurolite is most beautifully illustrated in the rocks round the Great Transvaal laccolite. The metamorphic rocks have been described by Hall[1] and I am greatly indebted to him for supplying me with material for study from this locality. The andalusite substance in the less advanced types settles as irregular patches in the shales, schists, sandstones, or whatever type of sedimentary rock is becoming metamorphosed. The minerals of the original rock are, as it were, pushed aside to make way for the introduction of the new material and no absorption is at first apparent. In more advanced types the minerals of the original rock are seen to be whittled away; usually there is an outer zone where the andalusite crystal is more or less free from inclusions. The developing crystals all tend to form in about the same dimensions in the particular rock-type and it is a constant feature that the prism zone early asserts itself, the planes bounding the long axis of the crystal being quite sharp, whereas the basal planes are indefinite, at any rate in the Transvaal specimens that I have seen and in those described by Hall. The Transvaal andalusites apparently do not go beyond this stage, but the smaller variety of the substance, chiastolite, does form very definite, sharply bounded crystals. The section illustrated by Hall (*Survey Report*, Part I, Fig. 1) shows the developing chiastolite with the center still full of inclusions, the outer rim clear, and the complete crystals in which all but a small string of inclusions in the center has been cleared away.

For the later stages of the development of andalusite I will take the andalusite schist of George.[2] The occurrence is on the Zwart

[1] A. L. Hall, "The Geology of the Haenertsburg Gold Fields," *Report Geol. Survey, 1907*, Pretoria (1908), 43 ff.; "Contact Metamorphism in the Western Transvaal," *Trans. Geol. Soc. S. Africa*, Vol. XII, Johannesburg (1910), 119.

[2] E. H. L. Schwarz, "The Andalusite Schist of George," *Albany Mus. Records*, II, 164 (1907), Grahamstown.

River along the main road from George to Knysna, about 5 miles from the former place; there is a small granite dyke exposed on the road section piercing the mica schists belonging to the Malmesbury Formation; about 5 yards from the granite the rock suddenly becomes full of well-formed andalusite crystals about an inch in length. The crystals are coated with scales of mica and usually have drawn out extremities in which mica flakes and andalusite substance have not yet become separated; some crystals, however, are sharply terminated. At the actual contact there is a thin zone of Cornubianite, never more than an eighth of an inch in width, in which there are small crystals of andalusite averaging .7 mm. in length and .15 mm. in breadth. Eye-shaped patches of the same substance occur where the schist has been kinked, and both crystals and "eyes" contain pellucid egg-shaped grains of quartz and a little red-brown mica, all that is left of the original sand grains and mica-flakes of the original rock. Occasionally a mica-flake of the schists ends abruptly at the margin of the andalusite, and in the latter there is the continuation of the flake rounded off in the usual manner of these inclusions; the flake has the appearance of having had its end melted and a portion incorporated in the new crystal of andalusite. When the crystals of andalusite have sharp ends, the dome faces are not equally developed on either side of the end; they follow the sides of the original kink of the shale in which the substance has been deposited, as if the crystal were monoclinic—another instance of the feebleness of the crystallizing force in the terminations as compared with the sides.

The larger crystals may be divided into the perfect forms and the irregular ones. In a longitudinal section of the former the substance of the andalusite is transparent with the usual pleochroism. Trains of rounded black dots and stout, short rods of rutile follow more or less the direction of the planes of parting. The black dots are graphite showing in reflected light an adamantine luster with white faces; they are probably carbonaceous matter that has aggregated in the andalusite substance from the flocculent material in the schists. The rutile needles also appear to have been enlarged from the minute ones in the biotite flakes. Rounded flecks of red-brown mica occur throughout the substance as well as the egg-

shaped pellucid quartz grains; these are the remnants of the minerals of the schists digested and almost absorbed. In the irregular crystals trains of unaltered mica-flakes pass right across the prisms, but in the perfect crystals these "segregation bands," as they would be called in igneous rocks, have been broken up and digested in the main. In many sections, however, little rounded specks occur which, under the microscope, appear as little xenoliths of the country rock. The andalusite, unable to penetrate and rid itself of these remnants, has tied up the indigestible substance in little rounded pockets, which may be as much as 1 mm. in diameter.

The andalusite substance apparently came from the granite, because it occupies spaces originally taken up by minerals of varying composition; some of the substance of the matrix has undoubtedly contributed to the building up of the andalusite crystals, but the part represented by the potash, iron, and magnesium of the biotite and by the potash of the muscovite must have been replaced by new material. There is further reason for believing that the new substance came from the granite, because in Stellenbosch, under precisely similar conditions, large feldspar crystals develop. Now the granite at George is a muscovite granite and would want all the potash for its own minerals, and therefore passed out aluminium silicate, but the Stellenbosch granite is a biotite granite and therefore could spare the potash, hence it passed out potash aluminium silicate.

THE ACID RESIDUE AFTER ABSORPTION

It will be evident from an inspection of the photographs accompanying this paper that the sediments have been dissolved by the dolerite, and from the analyses given it is apparent that the siliceous residue has been removed. Where has it gone to? As there are only channels of communication downward, the answer is that the siliceous material has gone toward the deeper portions of the earth's crust and there solidified. The granite bosses of the western province of Cape Colony represents the siliceous residues; they originally had Karroo sediments above them, probably with dolerite intrusions. In the Cape Town granite there are dolerite dykes associated with the granite, which go right up through the Table

Mountain sandstone.[1] I do not, however, wish to include in this discussion the question of the granite bosses as I have no new studies on them to offer, but the evidence for the absorption of sediments is very plain, especially along the granite contact at Sea Point, which was used by Hutton in illustration of his principles, and at Robertson, where the granite is bordered by a rim of *lit-par-lit* injection and other phenomena that I believe will afford positive evidence for the part these masses played in the general igneous injection of the country, when the material is worked up.

The igneous rocks of Cape Colony are very simple—enormous tracts of dolerite above and granite below; there are none of the complicated varieties to obscure the main principles. There is a curious side-issue in respect to the injection of andalusite crystals or occasionally orthoclase crystals in the sediments round the granite.[2] I assume for the purpose that the evidence for the absorption of sediments by the granite is as complete as for the dolerite, at least in Cape Colony, and that the original magma plus the material absorbed separated into dolerite and granite. We do not at present know what the proportions of basic and acid rock were, but we can suppose that they were equal. If, now, we take the mean of any analyses of normal granite and dolerite and contrast it with the analysis of any non-calcareous slate, adding a little sandstone if the silica percentage is small, we shall find that the excess of material after the igneous rock has used up all it wanted, consists of silica, alumina, and potash, and naturally, if the igneous rock is locally rich in potash, then of silica and alumina only. That is to say, the very general injection of silicate of alumina in the form of andalusite, chiastolite, and sillimanite, and the fairly common injection of orthoclase crystals, would be a result of the absorption of the slates and the rejection by the granite-dolerite magma of waste material. I take as an illustration the analyses given in Professor Judd's *Students' Lyell*, which can easily be checked. A more suitable series of analyses would be the slates intruded by the granite, the granite and the dolerite dykes in the granite, which

[1] See F. H. Hatch and G. S. Corstorphine, *Geology of S. Africa*, Figs. 2 and 3; pp. 37 and 41.

[2] E. H. L. Schwarz, *Ann. Rept. Geol. Comm., 1897*, Cape Town (1899), 54.

occur on the Wynberg side of Table Mountain, but I have not the material before me; a large number of similar series of analyses that I have tried give the same result.

	Granite	Dolerite	Mean	Mica-Schist	Excess after Absorption
SiO_2	76.1	50.2	63.1	66.2	3.1
Al_2O_3	13.4	15.0	14.2	18.6	4.4
FeO, Fe_2O_3	1.3	16.9	9.1	5.3	...
MgO	.2	5.8	3	1.2	...
CaO	.3	10.5	5.4	.4	...
Na_2O	3.1	2.2	2.6	2.2	...
K_2O	4.9	1.4	3.1	3.9	.8

THE RESEMBLANCES BETWEEN THE DEVELOPMENT OF ANDALUSITE CRYSTALS AND IGNEOUS INJECTION

In the case of the George andalusite we have a crystal substance injected into a rock. It first occupies cavities ready made for it, then with accession of further material, it dissolves, or as we should say in speaking of igneous rocks, melts up portions of the invaded rock, assimilates suitable substances and passes out the residue. Segregation bands develop where conditions are unfavorable, and included blocks or xenoliths entirely unaltered or more or less "metamorphosed" occur. All the phenomena of igneous injection are portrayed without the aid of any great heat, though hot water circulating under pressure was no doubt the agent by which the transference of material was accomplished. In the constancy of size also the masses of igneous rocks are simulated. The Zwart River crystals are about an inch in length—4 cm. perhaps would be the best average. None are much smaller or larger. A little farther on a similar but less perfect development of crystals occurs where the size is half that of those of the Zwart River material, and again in the chiastolite slates of the Transvaal a much smaller average is attained. So throughout the Karroo the dykes and sills are very constant in thickness; the laccolites of the Drakensberg Plateau and the granite bosses of the southwest are of approximately equal bulk. The granite masses of Cornwall and Devon are another striking example. It would seem that as with crystals so with magmas, there is a limit of size.

THE CHANNELS BY WHICH THE ACID RESIDUES ESCAPED

The escape of siliceous material from the dolerites should leave somewhere some trace. As the channels of supply function at the same time as conduits for the waste material, there should exist occasionally composite dykes of the type described from Canada by Lawson,[1] and from Norway by Vogt,[2] which have basic margins and granite or syenite centers. Similar ones occur in Arran consisting of selvages of augite-andesite and centers of quartz-felsite as described by Judd.[3] They have also been found in Skye and the Thüringer Wald.[4] No dykes of this nature have so far been noticed in South Africa, but diorite dykes genetically related to the dolerite sills are fairly common about Cradock and Kentani. A pair of parallel dykes in the Transkei were described by Dr. Rogers and myself in 1901; they run a little north of the Quizzyhota, cross the Kei, and traverse the Kentani district to its eastern border along the Kogha River; the easy weathering of this rock as compared to that of the dolerite and Karroo sediments has left deep furrows in the land, which have been given the local name of the "Transkei Gap."[5] Another diorite mass occurs at Gonubie along the main road from Kei Road to Komgha. The Gap-rock was described by Dr. Rogers in the paper referred to, and I reproduce it for comparison with the description of the dolerite of the Quizzyhota.

The rock forming the dykes of the Gap is a peculiar one, differing in important respects from any intrusions hitherto found by us in the Karroo Formation, although as will be pointed out in the following notes, it has a distinct relationship to the olivine-dolerite of the sheets.[6] It consists chiefly of the following minerals in the order of their usual relative abundance: plagio-

[1] A. C. Lawson, *Report on the Geology of Rainy Lake Region, Geol. and Nat. Hist. Survey, Canada* (Ann. Rept., 1887–88), Part F.

[2] J. H. L. Vogt, *Geol. Mag.* (1892), 82; W. C. Brogger, *Eruptivgesteine des Kristianiagebietes*, I (1894), 56.

[3] J. W. Judd, "Composite Dykes in Arran," *Q.J.G.S.*, XLIX, 545 ff.

[4] A. Harker, *Tertiary Igneous Rocks of Skye*, chap. xii.

[5] A. W. Rogers and E. H. L. Schwarz, "The Transkei Gap," *Trans. Phil. Soc., S. Africa*, XIV. (Cape Town, 1901), 63.

[6] The olivine-dolerite which forms the intrusive sheets of the Transkei is very like the rocks occurring in the same manner near Beaufort West, and described by E. Cohen, *Neues Jahrb.* (1874), 195.

clase, hornblende, augite, quartz, red-brown mica, orthoclase, apatite iron ores, sphene and decomposition products such as chlorite, uralite and calcite. Variations in the proportions of these minerals show that the rock differs considerably in composition from point to point.

The plagioclase has almost always a zonal structure; . . . . it frequently shows crystal outlines when in contact with the hornblende and augite, sometimes small crystals of the feldspar are entirely inclosed by the hornblende and augite. This ophitic structure though found without difficulty in all slices of the rock examined, is not nearly so pronounced a feature as in the olivine-dolerite.

The original hornblende is mostly of a pale greenish-brown colour, with feeble pleochroism, but a bright green strongly pleochroic variety also occurs, sometimes forming part of a crystal which is mostly made up of the pale kind. Occassionally small crystals showing the prism faces are met with, but the larger plates seen in the slices are always irregularly bounded by contact with other minerals, notably plagioclase. The last remark applies also to the augite, which is colourless in section and appears to be identical in character with the augite of the olivine-dolerite. The hornblende and augite usually occur together, intergrown with their orthopinacoidal faces parallel. The augite often forms the inner part of a section of the two minerals; outside this area the hornblende encloses the whole. The structure is easily seen by ordinary light under the microscope, as the augite is colourless and the hornblende pale greenish-brown, but between crossed incols the minerals are still more clearly seen owing to their extinguishing in different positions of the nicols. The intergrowths of the two minerals are sometimes twined, the composition plane being the ortho-pinacoid, common to both minerals.

Hornblende is rarely found in the olivine-dolerites but it does occur in them, *e.g.*, in the coarse olivine-dolerites of the sheet seen on the shore between the Gxacha and Kologha Rivers (Kentani) and in the Kologha sill. In a slice from the dolerite sill exposed along the Kei River at Mimosa Hill (the Kologha sill) there is much hornblende of the same variety as that in the Gap-rock and it is also intergrown with augite.

The mica is a red, strongly pleochroic variety, frequently altered to a very pale, greenish mineral with weak double refraction. It frequently encloses small zircons round which there is always a pleochroic halo; zircon occurs similarly in the hornblende. This mica occurs frequently and is a most important constituent of the Gap dykes; a precisely similar variety is found in almost all slices of the Transkeian olivine-dolerites but in very small quantity.

Quartz is abundant in some parts of the Gap dykes and present in all slides examined. It was the latest constituent to crystallise out from the liquid magma; it frequently forms a micropegmatitic intergrowth with a cloudy untwined feldspar which is probably orthoclase. Both micropegmatite and quartz are occasionally seen in the slices of the dolerites, but they are generally very subordinate constituents of the rock.

The iron-ores are magnetite, ilmenite with which sphene is often associated and iron pyrites. Apatite is always present, sometimes in considerable quantity.

The rock forming the dykes of the Gap may be called quartz-mica-augite diorite; it differs from the olivine-dolerite very considerably in the absence of olivine and in the presence of large amounts of hornblende, brown mica and quartz as well as the more acid varieties of plagioclase. It is very noticeable, however, that none of the minerals which characterise the Gap-rock are foreign to the olivine-dolerites and in the case of the Kologha sill the dolerite in parts approaches the Gap-rock in character rather closely by the increase in the amount of hornblende, red mica and the zoning of the plagioclase. The affinity between the two rocks is sufficient to make it preferable to regard the Gap-rock as derived from the magma which supplied the dolerite intrusions rather than the result of a quite different order of events. If we consider the Gap-rock as a late product of the magma after the dolerite had been got rid of, our view will explain the facts observed under the microscope and in the field; for while the evidence of a microscopic examination shows that the Gap-rock and the dolerite are genetically related, the field evidence conclusively proves that the latter rock had solidified before the former was intruded through it.

I do not think the last-mentioned fact invalidates the present view that these diorite dykes are the channels of escape of waste siliceous material as well as supply dykes of basic material. The dolerite spreads upward and the conduits of the upper sills must have remained open after the consolidation of the lower sills. There has been noted also a sequence in the infillings of the composite dykes of Arran and Skye. It may be noted that in the latter locality, where the granite invades the gabbro, it often partially fuses it and converts it into a rock consisting of hornblende and feldspar (labradorite to oligoclase).[1] At any rate the absorption of the sediments by the dolerite necessitates the escape of siliceous material, and the diorite dykes, where the differentiation into an acid and basic series has not been completed, are of the necessary constitution. The fact that the diorite dykes have been noticed where there is great development of laccolites, as at Cradock and in Komgha, is of special importance. The ordinary sills of the Karroo have been intruded for miles along inclined planes and, as the thickness of the dykes and sills varies very little, the diffusion of the acid and basic parts of the magma would have been unrestrained. In the laccolities, however, which form great lumps with

[1] A. Harker, *Tertiary Igneous Rocks of Skye*, 171.

comparatively narrow supply dykes, the channels of supply and escape of waste siliceous material are so small that the diffusion of the substances in the magma would have been hindered and as a result these dykes consolidated with rocks of the average composition.

THE DIFFUSION DUMBBELL

Taking the whole evidence which the granite bosses, the diorite dykes and the dolerite laccolites afford us in Cape Colony, one is led to conceive of a system of igneous injections of a dumbbell shape. Below we have the Malmesbury clayslates, above the Karroo sediments, in between the various siliceous sediments of the Cape system, or sometimes in the north of the Pal-Afric group Kheis quartzites and Pretoria iron-bearing quartzites. Below, the magma eats out great holes and fills them with granite; above, the same magma eats out the holes and fills them with basic rock. In between are thin dykes of communication usually dolerite but uuder certain conditions diorite. The slates above and below became absorbed and the material from both was added to the general stock of magma. The average magma remained fluid in this dumbbell system for some time, till for some reason the acid part concentrated in the lower part and the basic in the upper part, the diffusion taking place through the narrow part of the dumbbell and sometimes the average magma became caught in this part and became consolidated as diorite.

The facts are plain enough and it is perhaps as well to content oneself with them at present, but there is an explanation which, if only speculative, may be worth mentioning in order to show that this differentiation of an average magma is not wholly unexpected.

THE IONIC SEPARATION OF SUBSTANCES IN A ROCK-MAGMA

When an iron-bearing rock weathers at the surface of the earth, the iron does not travel outward to the sea along with the soda, lime, and potash but seeks the center of the earth.[1] The fact is easily recognizable in the replacement of limestone by iron ores,

[1] E. H. L. Schwarz, *Causal Geology* (1910), 73; "Selective Absorption of Substances in the Earth's Crust," *Journal Assoc. for Advancement of Science, S. Africa* (Cape Town, 1912), 181.

which are of common occurrence; in these cases certain conditions have caused precipitation of the iron from solution, but where the conditions are not favorable, the iron goes on its journey downward toward the base of the crust. Weak solutions such as these which carry the iron are ionized and the metallic ion carries a positive charge of electricity; the metallic ion possibly is attracted by the magnetic core of the earth, but however that may be, the iron goes down and must come to rest in the base of the crust beyond which water cannot penetrate. This would lead to an accumulation of a positive charge at the base of the crust. Above this is suspended a solution or a fluid magma which is an electrolyte,[1] that is, one in which the substances are ionized and the metallic ions carry a positive charge and the acid ions a negative one. Under such circumstances the negative, acid ions would be attracted by the positive charge at the base of the crust and the metallic, positive ions would be repelled, and in that way a magma of average composition would be differentiated into an acid and basic series, the acid part accumulating in the lower half of the dumbbell and the basic in the upper. Whether this cause is sufficient for the effect I do not know, but considering the immense time during which geological phenomena take place, a small but persistent electrical attraction and repulsion, such as exists under the circumstances, would have far-reaching effects.

[1] C. Barus and J. P. Iddings, *Amer. Jour. Sci.*, XLIV, 242.

AN ACCESSORY LENS FOR OBSERVING INTERFERENCE FIGURES OF SMALL MINERAL GRAINS

ALBERT JOHANNSEN
University of Chicago

As long ago as 1880 Bertrand[1] discovered that in the bubbles which are found so frequently in the Canada balsam between the mineral section and the cover-glass, there may be seen an interference figure of the mineral lying below it. The bubble acts as a lens of short focal length and takes the place of the objective, while the ocular and objective combined act as do the Bertrand lens and the ocular in the usual method of observing interference figures.

Later, Schroeder van der Kolk[2] carried this method a step farther. He placed a drop of glycerine upon the cover-glass of the slide to be examined and stirred it rapidly with a thin rod so that it became filled with small bubbles. Over this he placed a cover-glass and, between crossed nicols and with a medium-power objective, he depressed the tube a very little below the focal plane and found in each bubble a small interference figure. To avoid the necessity each time of preparing anew a glycerine foam, Schroeder van der Kolk used the following simple device: He placed a drop of Canada balsam on an object-glass and, if necessary, cooked it. After producing foam by rapid stirring, he placed a cover-glass upon it and the instrument was completed. To use it he placed it, cover-glass downward, upon the rock section and shoved it into such positions that bubbles appeared over the desired spots.

In using this method, the present writer found that he could not produce bubbles in well-cooked balsam. If undercooked, the gum would squeeze out at the sides and stick to the rock slice under examination and the bubbles would become distorted from their

[1] E. Bertrand, "De l'application du microscope à l'étude de la minéralogie," *Bull. soc. min. France*, III (1880), 93–96.

[2] J. L. C. Schroeder van der Kolk, "Ueber eine Methode zur Beobachtung der optischen Interferenzerscheinungen im convergenten polarisirten Lichte, insbesondere in Gesteinsschliffen," *Zeitschr. f. wiss. Mikroskop.*, VIII (1891), 459–61.

spherical form. Another objection is that the extra cover-glass increases the distance between the balsam film and the mineral and, as a consequence, a dark border surrounds each bubble and cuts down, materially, the size of the interference figure. If a piece of glass, full of minute bubbles and of the thickness of a cover-glass, could be prepared, it would be a great improvement. By removing the cover-glass of the rock section to be examined and pressing the new glass down over it on a drop of oil, the interference figures would appear sharp, of the full size of the bubbles, and without a dark border. Having no such glass the writer has prepared small lenses as follows:

A glass rod was heated over a Bunsen burner and was drawn out as thin as possible. Pieces of the glass threads thus obtained were again heated and again drawn out to hair-like thinness. These were broken into lengths of an inch and a half and the extremities held an instant in the edge of the flame, whereby truly spherical globules were produced at each end. After preparing a number of these spherical lenses, they were examined under the microscope and all that were not perfect or which contained bubbles were rejected. Likewise only those which had a diameter of less than $\frac{1}{125}$ of an inch (0.2 mm.) were retained. If, now, such a lens is placed directly in contact with the cover-glass over the mineral to be examined, and the microscope arranged with crossed nicols, ocular, and a medium- or low-power objective (No. 0 to 4, Fuess), there will appear in it a small but perfect interference figure. The microscope should be focused upon the glass sphere and the tube then slightly raised. A condensing lens is not necessary but without it part of the figure is cut off by the dark border. The optical character and dispersion can be determined as well by this method as by the use of a Bertrand lens, and the figure is decidedly sharper. By its means it is possible to examine the interference figures, undisturbed by surrounding minerals, of grains smaller than is possible by the Lasaulx, Klein, or Bertrand methods, and it possesses the further advantage that the mineral and the interference figure can be seen at the same time. By shifting the lens, the optical orientation of all of the grains in a section can be determined. When used in connection with the Fedorow universal

stage, interference figures may be obtained with low power objectives. This extends the usefulness of the Fedorow stage since it increases the rapidity with which determinations may be made in certain cases.

To permit the rapid examination of a slide the writer attaches a bit of soft modeling-wax to one side of the stage and in it places the glass thread at such an angle that the lens globule is in the center of the field and rests against the cover-glass of the mineral section. The latter may now be shifted around the stage as much as is desired, bringing, successively, the different mineral constituents under the lens, which remains undisturbed in the center of the field. Another method is to attach the rod of the lens to the rim of a cork ring, allowing it to project toward the center, and so tilted that it rests on the same plane as the bottom of the ring. This method better protects the delicate glass rod but is not quite so convenient, since both rock section and cork must be moved when it is desired to place different minerals in the center of the field.

Reviews

Geology of the Haliburton and Bancroft Areas, Providence of Ontario. By Frank D. Adams and Alfred E. Barlow. Ottawa: Canada Department of Mines, Memoir No. 6. Pp. 419; 70 photographic illustrations, 7 figures, 2 maps.

The Haliburton and Bancroft areas described by Adams and Barlow are located in the southeastern part of Ontario within the Canadian Protaxis. They constitute a pre-Cambrian complex of about 4,200 square miles, of which the southern portion, the Bancroft area, consists mainly of limestone and dolomite, with minor clastic sediments, intruded by syenites, gabbros, and diorites, and intercalated with acid eruptives, the whole invaded by an enormous batholithic development of granite gneisses and granites, exposed mainly in the Haliburton area to the north, and making up more than half of the total extent of the region. This complex was intricately folded in pre-Cambrian times, mainly under conditions of flow contemporaneously with the intrusion of the granite gneisses and granites, the major axis of deformation being N. 30° E.

Like most of the Protaxis, this region is beveled by a nearly level plane of erosion whose inequalities result from etching and the unevenness of glacial deposition. Here and there monadnocks of igneous rock rise to a height of several hundred feet above their surroundings. To the south, this surface dips under nearly horizontal Paleozoic limestones beveled by a much smoother plain. The fertility and cultivation of the conspicuous, steep-faced outliers of Paleozoic limestones studding the boundary, contrast strikingly with the more sparsely settled, slightly tilted pre-Cambrian, much of which is a succession of low, rolling, barren knobs of rock rising from a bowlder-strewn waste, whose drift and rock depressions are frequently occupied by lakes or swamps. Green, unbroken forests still withhold a portion of it from the desolateness to which it is doomed, a land in which canoe and trail are still necessities of travel. From the Paleozoic front, the undulating plain which bevels the pre-Cambrian rocks rises toward the northeast, with a gradient of about 8 feet per mile, to a wavy line of maximum elevation of about 1,500 feet trending a little south of east through the northern part of the

Haliburton area. From thence it descends toward the northeast, thus dividing the drainage to the south and west into the St. Lawrence system and to the north into the Ottawa River. Both the configuration of the lakes and the direction of the streams is guided to a large extent by the foliation of the rocks. This is especially true of the limestone area while the drainage lines on the granite gneisses show much less dependence on tectonic lines.

The limestones and dolomites of this region are a part of a pre-Cambrian limestone terrane stretching from Georgian Bay to beyond the St. Maurice River in the Province of Quebec. In the contiguous area to the southeast of the Haliburton and Bancroft areas, Logan's Hastings district, these limestones and dolomites, while containing basic intrusives, are less highly altered than in Logan's Original Grenville of Quebec, where they are intruded and intensely altered by the same granite gneisses which invade them in the Haliburton and Bancroft areas. Since the less altered limestones of the Hastings district grade into the highly altered limestones to the northwest without divergence of strike and without the interposition of basal conglomerates, or other evidences of unconformity, Adams and Barlow believe that the entire terrane constitutes one series to which they give the name Grenville, and with this they correlate the limestones of the Adirondacks, thus grouping as one, an areal exposure of 83,000 square miles of limestone, one of the greatest developments of limestones in North America, and the greatest in the pre-Cambrian. The existence of certain conglomerates in the Bancroft area, however, has caused Miller and other geologists to suspend judgment as to the unity of this region.

The position of the Grenville Hastings series in the pre-Cambrian is still left in doubt since they have not been found to connect with any of the correlated units. Nor do they resemble any of them lithologically. In the linear character of their topography and in their great dominance of sediments, they are more like the Algonkian than the Archean. Adams and Barlow class them as Archean, evidently using the term as synonymous with pre-Cambrian.

The basement on which the sediments rest has nowhere been found. Adams and Barlow, however, follow Lawson in their belief that in cases like this, the sediments were deposited on the granites and that later the granite basement became re-fused and intruded into the sediments.

The thickness of the sediments in the Haliburton and Bancroft areas is estimated by the authors to be about 17 miles, though they recognize the probability that isoclinal folding and other factors may

have added to the apparent thickness. One feels rather quizzical at the confidence with which they present this figure.

The least metamorphosed, pure limestones are mostly fine-grained, and of a bluish color, the dark color being due to organic matter. They are interstratified with dolomitic and magnesian beds, but the pure limestones dominate. This great development of pure limestones modifies the prevailing opinion that the pre-Cambrian does not contain many pure limestones.

The magnesium carbonate is found to occur in the mineral dolomite, and as a slight replacement of calcium carbonate in calcite. All gradations are also found, from pure limestones to argillaceous and quartz-bearing limestones and dolomites, quartzites and paragneisses, but the impure rocks are highly recrystallized as a rule. Most of the limestones and dolomites have been intensely metamorphosed, but the relative importance of intrusion and of intense folding in bringing this about is not always clear. The carbonates have adjusted themselves to stress strain conditions by plastic flow, including recrystallization, gliding, shearing, and granulation. In general the limestones were more plastic than the silicate or quartz rocks associated with them, flowing in between the fragments of the latter.

The most apparent effects of metamorphism on the limestones are a coarsening of the grain, and a change of the color from blue to white, and the development of graphite, complex silicates, and heavy oxides. Pyroxenes, amphiboles, feldspar, epidote, quartz, scapolite, magnetite, spinel, and many others are more or less common developments. There is also a notable series of sulphides, among them mispickle, galena, pyrite, molybdenite, orpiment, and realgar. To what extent these new developments represent recrystallization of materials originally present and to what extent infusion of new materials is not clearly determined. Where the limestones have been invaded by basic intrusions and, on a much larger scale, where they have been invaded by the granite gneisses, they have been altered either to a granular aggregate of pyroxenes and hornblende, with scapolite and accessory minerals, or to a feather-like aggregation of hornblende with other silicates and residual calcite and dolomite. To these rocks, approximating the composition of diabase, the name of amphibolites have been given. The granite gneisses are also full of amphibolite inclusions most of which probably represent altered limestones. From a comparison of the composition of three amphibolites, representing different stages of the alteration of limestones by granite gneiss intrusion, the authors conclude that the process of

amphibolitization involves first a loss of carbonates and a development of feldspar and pyroxene in their stead. In the second stage all carbonates are replaced by pyroxene, feldspars, and scapolite, and finally the rock becomes in texture like a fine-grained igneous rock composed of feldspars, hornblende, and pyroxene. Without presenting analyses of the fresh limestones, the authors assume that this change involves loss of lime and carbonic acid from the limestones and transfusion of silica, alumina, iron, and magnesia with some alkali and titanic acid from the granite to the limestones. From the data presented this conclusion is only valid if the change took place without loss of mass. The limestones and dolomites are also altered in many places to serpentine marbles. Microscopic studies show, however, that the change to serpentine is preceded by the development of other silicates such as pyroxenes and amphiboles.

The gabbros and diorites occur either as stock-like masses piercing the limestones and altering them to amphibolite, or as dikes cutting the limestones, and as sheet-like masses whose relation to the limestone is uncertain. Some of the latter may be altered pyroclastics. The dikes and sheets have the character of granular amphibolites.

Relatively small masses of acid volcanic orthophyre with distinct flow structures are intercalated with the limestones.

The nepheline corundum-bearing syenites occur between the granite gneisses and the limestone and with one exception within the limestones, thus seeming to corroborate Daly's hypothesis of the genetic relationship of syenites to limestones. All contain limestone inclusions. Certain phases consist largely of nepheline with few femic constituents, others almost entirely of femic minerals, while in some plagioclase feldspar is the dominant mineral.

The greatest petrographic unit of the area, the granite gneisses, presents three principal phases. About 82 per cent of its area, the red gneisses, is composed mainly of oligoclase, with some potash feldspars, quartz and femic accessories; the remainder of the area consists of gray gneisses, high in femic constituents, and amphibolite inclusions, derived mainly from the metamorphosed invaded limestones. The amphibolite inclusions vary in extent from acres to minute lenses, and present all stages of dissolution. Some are still angular and massive, others are pierced by pegmatitic phases of the granitic magma, while pieces which have flowed many feet from each other are separated by fine-grained gneiss. Clear cases of the solution of the amphibolites in the granites, while uncommon, suggest that some of the gray gneisses may have developed in this way. In general, however, the amphibolite inclusions

have not become gneissose, and were much more brittle than the relatively plastic granite gneisses in which they flowed.

A minor occurrence of very acid gneissic red granite, consisting dominantly of potash feldspar and quartz, was found to contain nodules and small vein-like masses of zonally arranged quartz sillimanite and tourmaline, which are regarded by the authors as acid differentiates and not as inclusions.

The alignment of the granite gneiss batholiths with the major axis of folding, and the parallelism of the foliation and folding of both sediments and intrusions, indicates that the invasion of the granite gneisses and the deformation of the region was largely contemporaneous. Intrusion was effected by the up-bowing of the sediments, and by the invasion of the magma as a pegmatitic facies into the shattered sedimentary border zone, or by *lit-par-lit* intrusion, followed by the stopping-off of the intruded rocks into the magma. Solution of the sediments was a very subordinate process.

The authors believe that the granite gneisses were in a partially crystallized but pasty condition when injected, as shown by their flow lines, the granulation of the feldspars, and the elongation of the more plastic quartz crystals. While most of the deformation of the granite gneisses took place without fracturing, other than the granulation of mineral particles, some of the sharp folds grade into faults, or shear zones which are invariably filled with granite pegmatite. Many of the granite pegmatitic veins in shear zones and in the border zones of the sediments were intruded before deformation was completed, and became granulated and sheared into pseudoconglomerates, while others were injected after deformation was completed and show no fracture or distortion.

The principal exploited economic mineral of these areas is corundum from the syenites. Gold and copper-bearing veins are also known to dissect the amphibolites, while magnetite is found as a segregation in the syenites and in bands in the stratified amphibolites. Apatite and graphite-bearing pegmatites cut the limestones, and graphite also occurs in lenses parallel with the stratification of the limestones. Post-glacial deposits of marl and ochre have been located, and building stones in the form of marble, serpentine marble, and sodalite are described as valuable but as yet undeveloped resources.

This report is rich in illustrative and descriptive information on the mechanics of intrusion, the adjustment of materials to stress strain conditions, magmatic differentiation, and on contact metamorphism. If anything, it may be mildly criticized for too much detail. In order

to get at the essentials, the reader is often obliged to skim over many superfluous details on the optical properties of minerals. Some of the important conclusions may be open to the objection that they are based on insufficient evidence; namely, the great thickness and conformability of the sedimentary series, and the transfusion of certain materials from the granite gneisses to the limestones. EDWARD STEIDTMANN

[*Author's Abstract*]

Production of Graphite in 1911. By EDSON S. BASTIN. Advance chapter from Mineral Resources of the United States, 1911. U.S. Geological Survey.

The natural graphite mined and concentrated in the United States is variable in amount, principally because the process of milling flake graphite, the most abundant type of domestic material, is still in an experimental stage. Because of this unreliability of the domestic supply most of the large consumers of graphite prefer to depend for their supply on imported material.

In 1911 the quantity of graphite imported into the United States for consumption was 20,702 short tons, valued at $1,495,729. In contrast to this the total domestic production was 3,618 short tons of natural graphite, valued at $288,465, and 5,072 short tons of manufactured graphite, valued at $664,000.

The great bulk of the graphite imported into the United States comes from the island of Ceylon, and the United States has for many years been the principal market for this Ceylon product. Considerable amounts of graphite are also imported into the United States from Mexico and within the last few years graphite from Chosen (Korea) has entered the market.

The principal feature of this report as distinguished from previous reports on the production of graphite in the United States is a summary of existing knowledge in regard to the famous graphite deposits of the island of Ceylon. The literature concerning these deposits is widely scattered, mostly in obscure publications. The geological occurrence of the Ceylon graphite, method of working the deposits and of preparing the graphite for the market are discussed, and the various theories which have been advanced to account for their origin are summarized. A list of the principal publications dealing with these deposits is included.

The report also describes a somewhat similar occurrence of graphite near Dillon, Mont., and concludes with a bibliography of all of the important publications dealing with the graphite deposits of the United States.

ANNOUNCEMENT

THE arrangement between the University of Chicago and the University of Cambridge, by which the latter is given the exclusive agency in the British Empire for the former's publications, is now being supplemented by a reciprocal agreement, the Chicago institution taking over the American agency for a number of the Cambridge publications. An arrangement has already been concluded for the Cambridge journals, and the following periodicals in the future will be issued in America under joint imprint: *Biometrika; Parasitology; Journal of Genetics; The Journal of Hygiene; The Modern Language Review; The British Journal of Psychology; The Journal of Agricultural Science.*

Several new books from the Cambridge list are also to be taken over at once and published in this country under joint auspices. The list includes *The Life and Letters of Lord Hardwicke*, by M. Philip Chesney Yorke; *The Duab of Turkestan*, by W. Rickmer Rickmers; *The History of Romanesque and Byzantine Architecture*, by Thomas Graham Jackson; and *The Genus Iris*, by William Rickatson Dykes.

The publications selected all embody the results of research. This movement toward a closer co-operation between the two universities is a matter that should be of interest to all who are concerned with the advancement of scientific and scholarly research and the preservation of its results. The difficulties involved in the publication of such material are too obvious to need comment, and it is to be hoped that an arrangement that promises so much aid in this direction may be further extended.

TEXTBOOKS *for* RELIGIOUS EDUCATION

PUBLISHED BY THE UNIVERSITY OF CHICAGO PRESS

CONSTRUCTIVE BIBLE STUDIES

KINDERGARTEN SERIES

The Sunday Kindergarten: Game, Gift, and Story. By Carrie S. Ferris.

Teacher's manual, $1.25, postpaid $1.40. Permanent equipment for each pupil, net $1.00, postage extra.

Temporary material (renewed each year) for each pupil, net 35 cents, postage extra.

ELEMENTARY SERIES

Child Religion in Song and Story. (The Child in His World.) By Georgia L. Chamberlin and Mary R. Kern.

Teacher's manual, $1.25, postpaid $1.40. Sunday Story Reminders, pupil's notebook, 40 cents, postpaid 45 cents.

Child Religion in Song and Story. (Walks with Jesus in His Home Country.) By Georgia L. Chamberlin and Mary R. Kern.

Teacher's manual, $1.25, postpaid $1.40. Pupil's notebook, 40 cents, postpaid 45 cents.

An Introduction to the Bible for Teachers of Children. By Georgia L. Chamberlin.

Teacher's manual, $1.00, postpaid $1.10. The Books of the Bible, pupil's notebook, 25 cents, postpaid 29 cents.

The Life of Jesus. By Herbert W. Gates.

Teacher's manual, 75 cents, postpaid 83 cents. Pupil's notebook, 50 cents, postpaid 58 cents.

Old Testament Story. By Charles H. Corbett.

Teacher's manual, $1.00, postpaid $1.09. Pupil's notebook, 50 cents, postpaid 59 cents.

Paul of Tarsus. By Louise W. Atkinson.

Teacher's manual, $1.00, postpaid $1.10. Pupil's notebook, 50 cents, postpaid 59 cents. Pupil's home-work book, 25 cents, postpaid 28 cents.

Heroes of Israel. By Theodore G. Soares.

Pupil's textbook, $1.00, postpaid $1.13. Teacher's manual, $1.00, postpaid $1.10.

SECONDARY SERIES*

The Gospel of Mark. By Ernest D. Burton.

Pupil's textbook, $1.00, postpaid $1.12.

Studies in the First Book of Samuel. By Herbert L. Willett.

Pupil's textbook, $1.00, postpaid $1.13.

The Life of Christ. By Isaac B. Burgess.

Pupil's textbook, $1.00, postpaid $1.12. Pupil's notebook, 25 cents, postage extra.

*Volumes from this group may also be used for more advanced grades or for adults.

The Hebrew Prophets, or Patriots and Leaders of Israel. By Georgia L. Chamberlin.
Pupil's textbook, $1.00, postpaid $1.15. Teacher's edition (ready in 1913).

A Short History of Christianity in the Apostolic Age. By George H. Gilbert.
Pupil's textbook, $1.00, postpaid $1.12.

COLLEGE, UNIVERSITY, AND ADULT SERIES

The Life of Christ. By Ernest D. Burton and Shailer Mathews.
$1.00, postpaid $1.14.

The Prophetic Element in the Old Testament. By William R. Harper.
$1.00, postpaid $1.10.

The Priestly Element in the Old Testament. By William R. Harper.
$1.00, postpaid $1.12.

Christianity and Its Bible. By Henry F. Waring.
$1.00, postpaid $1.12.

Social Duties. By Charles R. Henderson.
$1.25, postpaid $1.37.

Great Men of the Christian Church. By Williston Walker.
$1.25, postpaid $1.37.

A Short Introduction to the Gospels. By Ernest D. Burton.
$1.00, postpaid $1.07.

A Handbook of the Life of the Apostle Paul. By Ernest D. Burton.
50 cents, postpaid 54 cents.

AMERICAN INSTITUTE OF SACRED LITERATURE SERIES

Full courses, each 50 cents, postpaid 54 cents.

The Life of the Christ. By Ernest D. Burton.

The Foreshadowings of the Christ. By William R. Harper.

The Founding of the Christian Church. By Ernest D. Burton.

The Work of the Old Testament Sages. By William R. Harper.

The Work of the Old Testament Priests. By William R. Harper.

The Social and Ethical Teachings of Jesus. By Shailer Mathews.

The Universal Element in the Psalter. By John M. P. Smith and Georgia L. Chamberlin.
Half-courses, each 25 cents, postpaid 27 cents.

The Origin and Religious Teaching of the Old Testament Books. By Georgia L. Chamberlin.

The Book of Job, or the Problem of Human Suffering. By William R. Harper.

Four Letters of Paul. By Ernest D. Burton.

Address

THE UNIVERSITY OF CHICAGO PRESS - Chicago, Illinois

THE SUMMER QUARTER

The Calendar for 1913.—The First Term begins Monday, June 16, and closes Wednesday, July 23; the Second Term begins Thursday, July 24, and ends Friday, August 29, the Autumn Convocation being held on the afternoon of that day.

A Quarter of Regular Work for Credit.—In the personnel of the teaching staff, in scope and methods of instruction, and in credit-value the work of the Summer Quarter ranks with that of the other quarters of the academic year.

Limitation of Work, etc.—The student is limited to three minor courses for each term, or to three major courses for both terms. In special cases permission may be obtained from the deans to pursue an additional course, for which in the case of undergraduate students, a supplementary fee must be paid. Graduate and Law students are given larger privileges, and students in the College of Education may add one of the arts without additional fee.

Graduate Study.—College professors and school teachers, clergymen, and members of other professions, holding Bachelor's degrees from accepted colleges, may avail themselves of the facilities of the University to pursue advanced studies under the guidance of research professors in all the chief departments of investigation.

Biblical and Theological Study.—The Divinity School offers to professors of theology, to theological students, to ministers, to religious workers, and to others interested in biblical and theological study, introductory and advanced courses in all its departments.

Professional Courses in Law.—Students beginning the study of law, those in the midst of their professional studies at Chicago or elsewhere, and practicing lawyers are offered work of a thorough and systematic character.

Courses in Medicine.—College seniors planning to study medicine, students in medical schools, and practitioners will find the summer course in medicine admirably adapted to their needs. The Summer Quarter is of especial value to students who need to review and to make up work.

Educational Principles and Methods.—The courses of all departments have a bearing upon the work of teaching, but the courses of the College of Education are peculiarly adapted to the professional needs of teachers, both in primary and secondary schools. The work in the various shops affords unusually complete instruction in the industrial arts and crafts.

Public Lectures.—A series of public lectures, concerts, and other forms of entertainment is scheduled throughout the Summer Quarter, and affords opportunity to students to hear speakers of eminence and artists of distinction.

Chicago in Summer.—An agreeable summer temperature, spacious parks, notable libraries and museums, great industrial plants, typical foreign colonies, a number of Settlements, and other significant social institutions make Chicago a peculiarly appropriate center for study and investigation.

For full information address

THE UNIVERSITY OF CHICAGO
CHICAGO, ILLINOIS

Quantitative Classification of Igneous Rocks

Based on Chemical and Mineral Characters

With an Introductory Review of the Development of Systematic Petrography in the Nineteenth Century

By WHITMAN CROSS, JOSEPH P. IDDINGS, LOUIS V. PIRSSON, and HENRY S. WASHINGTON

THE BOOK presents in detail the new system of classification and nomenclature proposed by the authors. It contains a series of tables to aid in the calculation of mineral and chemical compositions of rocks, and a glossary of the new terms employed in the nomenclature. Having traced the development of petrography during the past century, the authors discuss the defects of the present system of classification, the basis on which a proper classification must be made, and the construction of the system proposed. The new nomenclature is then presented in full, including magmatic and rock names; and the last part of the book is devoted to methods of calculation, the tables, and the glossary. The book answers a need widely felt among petrologists in the last few years for a new petrographic system into which could be fitted the recent large additions to our knowledge of rocks.

286 pp., 8vo, cloth; net $1.75, postpaid $1.91

The University of Chicago Press
Chicago, Illinois

Outlines of Geologic History with Especial Reference to North America

Symposium Organized by
BAILEY WILLIS

Compilation Edited by
ROLLIN D. SALISBURY

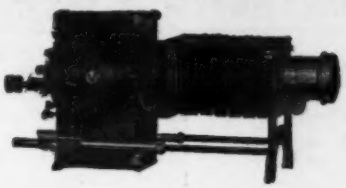
GEOLOGISTS and all readers of geologic literature will welcome the publication, in book form, of an important series of essays and discussions on the subject of geologic correlation under the title, *Outlines of Geologic History with Especial Reference to North America.*

They embody the present state of knowledge and opinion concerning many of the fundamental problems of North American geology, and form an admirable supplement to earlier treatises and manuals.

The value of the book is greatly enhanced by the fifteen paleogeographic maps by Bailey Willis which accompany the papers.

316 pages 8vo cloth $1.66 postpaid

The University of Chicago Press
Chicago - - - Illinois



The Successful Stereopticon

for educational work, lecture purposes, or home entertainment must be designed on a basis of greatest efficiency, simplicity of operation and of standard construction optically and mechanically.

And the stereopticon that best meets these requirements is the

Bausch and Lomb Balopticon

This popular projection instrument combines in high degree every requisite of the teacher, lecturer, or entertainer.

Its superior accurate lens equipment insures brilliant, sharply defined pictures, and its extremely simple operation makes it available for everyone. The careful construction and high-grade materials make it durable enough to last a lifetime.

Projects ordinary lantern slides and can be arranged also for photographs, postcards, etc.

Model C Balopticon—$25.00.

Opaque Attachment—$30.00.

Write today for Descriptive Circular 7D.

The Superior Quality of all Bausch & Lomb lenses, microscopes, field glasses, projection apparatus, engineering and other scientific instruments—is the product of nearly 60 years' experience.

Bausch & Lomb Optical Co.

NEW YORK WASHINGTON CHICAGO SAN FRANCISCO
LONDON ROCHESTER, N.Y. FRANKFORT

3

The University of Chicago

Offers instruction during the Summer Quarter on the same basis as during the other quarters of the academic year.

The undergraduate colleges, the graduate schools, and the professional schools provide courses in ***Arts, Literature, Science, Commerce and Administration, Law, Medicine, Education, and Divinity.*** Instruction is given by regular members of the University staff which is augmented in the summer by appointment of professors and instructors from other institutions.

SUMMER QUARTER, 1913
1st Term June 16—July 23
2d Term July 24—August 29

Detailed Announcements will be sent upon Application

The University of Chicago, Chicago, Ill.

ANIMAL MICROLOGY

PRACTICAL EXERCISES IN MICROSCOPICAL METHODS

By
MICHAEL F. GUYER
Professor of Zoölogy in the University of Cincinnati

An indispensable book for teacher, physician, student, or novice who wishes to learn how to prepare his own material for microscopical examination. There are special chapters on the preparation and examination of embryological material, blood, bacteria, and objects of general interest, and on the collection and preparation of material for the microscopical work in a course in elementary zoölogy. In an appendix nearly three hundred tissues and organs with directions for properly preparing them for microscopical study are tabulated. Sufficient account of the theoretical side of microscopy is given to enable the student to get satisfactory results from his microscope.

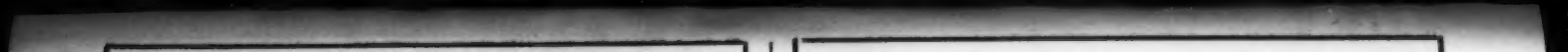
250 pp., 8vo; postpaid $1.88

THE UNIVERSITY OF CHICAGO PRESS
CHICAGO - - - - ILLINOIS

American Permian Vertebrates

By SAMUEL W. WILLISTON

THIS work comprises a series of monographic studies, with briefer notes and descriptions of new or little-known amphibians and reptiles from the Permian deposits of Texas and New Mexico. The material upon which these studies are based was for the most part collected during recent years by field parties from the University of Chicago. The book is offered as a contribution to knowledge on the subject of ancient reptiles and amphibians, with such summaries and definitions based chiefly on American forms as our present knowledge permits. The work is illustrated by the author.

228 pages *8vo, cloth* *Net $2.50* *Postpaid $2.68*

THE UNIVERSITY OF CHICAGO PRESS
CHICAGO - - - - - ILLINOIS